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Edited for the Council by J. LAURENCE PRITCHARD, Fellow

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NOTICES

Elections

The following Members were elected at a Council Meeting held on June 8th, 1926:—

Associate Fellow.—Mr. J. C. Stevenson.

Associates.—Mr. H. R. Haynes, Mr. P. H. Lindley, Mr. W. Ramsay and Mr. A. V. Tarlton.

Chairman

At a Council Meeting held on 8th June, Colonel the Master of Sempill, A.F.C., Associate Fellow, was elected Chairman to serve from October, 1926, to September, 1927.

Donations

The Council desire to acknowledge gratefully the gift of Journals from Sir Mackenzie Chalmers, Colonel J. D. Fullerton and Mrs. Waddell, also a donation of £6 from Flight Lieutenant E. C. Wackett for books for the Library, and some photographs and mementoes of the Lebaudy Airship from Sir Fabian Ware.

Students' Section

The Students' Section was reorganised in January with a view to the revival of its activities which had been in abeyance for nearly two and a half years.

Mr. S. Scott Hall was appointed Honorary Secretary and very largely due to his energy and enthusiasm the Students' Section has proved very successful. Lectures were given, after a preliminary discussion on "Air Travel," by Mr. M. Shadwell Hooper on Bernouilli's Theorem in Aerodynamics; by F./O. R. L. Ragg, R.A.F., on "Experimental Flying from the Pilot's Point of View"; by Mr. S. Scott Hall on "Stalled Flight"; and by Mr. R. Pierce on "Supercharged Engines."

Visits were paid to the London Terminal Aerodrome, Croydon; Messrs. de Havilland's Aircraft Works and Aerodrome; Messrs. Vickers' Aircraft Works; and to the Royal Aircraft Establishment, South Farnborough.

The attendances at the lectures and visits were good, and great keenness was displayed.

An important feature of the Session's work has been the introduction of an Appointments Board by the Council of the Society at the suggestion of the Students themselves. It is hoped, by this means, to place students and manufacturers in touch with one another.

It is hoped that next Session a more extensive programme and a greater range of activities will be arranged for.

Busk Memorial Prize

The names of prospective entrants for the Busk Memorial Prize must be received before September 30th. This prize, of a value of twenty guineas annually, has not yet been awarded, and only one entry for it has been received. It is very much hoped that some more members will send in papers for it this year. The regulations regarding the award may be obtained from the Secretary.

R.38 Memorial Prize

The R.38 Memorial Prize has been awarded to the paper "On the Calculation of Stresses in Rigid Airships," sent in by Professor R. V. Southwell, F.R.S., Associate Fellow. The paper will be published in the Journal in due course.

Associate Fellowship Examination

Provided that sufficient entries are received, the Society's examination for Associate Fellowship will be held on Monday, September 20th (Part I.), and Tuesday, September 21st (Part II.). Entry forms may be obtained from the Secretary and must be returned duly completed not later than Monday, August 23rd.

J. LAURENCE PRITCHARD, *Hon. Secretary.*

PROCEEDINGS

THIRD MEETING, SECOND HALF, 61ST SESSION.

A Joint Meeting of the Royal Aeronautical Society and the Institution of Automobile Engineers was held at the Royal Society of Arts on Thursday, February 4th, 1926, Colonel Tizard presiding.

The CHAIRMAN: It falls to me to-night to have the honour of welcoming on behalf of the Institution of Automobile Engineers and the Royal Aeronautical Society, a distinguished American engineer. Mr. Lawrance, who is the President of the Wright Aeronautical Corporation, is very well known as an aircraft engine designer; in fact, I think we should be correct in classing him among the pioneers in the development of radial engines of the air-cooled type. More than that, he has made a very close study of aerodynamics and for some time before the war he was engaged in investigations in collaboration with the Eiffel Laboratory in Paris. Thus we have a rather unique and rare combination of talents, and we shall listen with all the more attention to his paper on American aircraft engine development. I have great pleasure in calling upon Mr. Lawrance to give us his paper.

MODERN AMERICAN AIRCRAFT ENGINE DEVELOPMENT

BY CHARLES L. LAWRANCE.

In presenting a paper on the subject of Modern American Aircraft Engine Development, I propose to call your attention to some of the interesting and unusual features of our American engines, and briefly run over some of the engineering considerations which have led to the designs in question. For your convenience in following me, I am, first of all, giving you a table of engine data covering all engines now in general use, or shortly to be in production, in the United States. In this table you will note the last column on the right is devoted to "Power Plant Weight per Horse-Power." This term requires definition. As a manufacturer of, and a strong believer in, air-cooled aircraft engines, I would not be giving a fair comparison between the various types listed unless I took into consideration the weight of the water, piping and radiator necessary to complete the water-cooled power plant. I have assumed 0.6 pounds per rated horse-power for cooling systems for water-cooled engines, which is probably about the average. The term "Power Plant Weight" then, is the weight of the bare engine for air-cooled engines, and the weight of the bare engine plus 0.6 pounds per horse-power for water-cooled engines.

Turning first to the water-cooled engines, we find six engines, the two Packard engines, of 1,500 cubic inches and 2,500 cubic inches respectively; the Wright-Tornado, of 1,947 cubic inches; the Liberty; the Curtiss D-12 and the Curtiss V-1,400. These engines range from 420 horse-power to 800 horse-power; the Liberty being rated at 420 horse-power, the Curtiss D-12 at 430 horse-power, the Curtiss V-1,400 at 500 horse-power, the smaller Packard at 510 horse-power, the Wright-Tornado at 600 horse-power and the larger Packard at 800 horse-power. It will be noticed that, with the exception of the Liberty, these are all 12-cylinder, 60-degree V type engines, and that the new Curtiss V-1,400 and the two Packard engines are the lightest, these three being the latest water-cooled

engine developments in the United States. They are all noteworthy for their compact form and small over-all dimensions, the details of which I shall touch upon later.

The most interesting feature of the majority of these engines is the cylinder construction, particularly that of the two Packard engines, which have been designed by Mr. L. M. Woolson. In some ways these are a great departure from current practice. You will note the steel cylinder and steel head, which is made with four annular protuberances surrounding the four valve seats. To these is welded a steel plate on which the valve ports and operating mechanism are bolted. You will notice in this construction that the valve seats are very rigid, due to the circular ribs forming gas passages; and that the gasket between the valve port and cam housing has only the functions of an inlet, exhaust and water gasket and does not have to resist any high pressures. The cylinders are individual, with a very small water space, allowing a very close cylinder spacing.

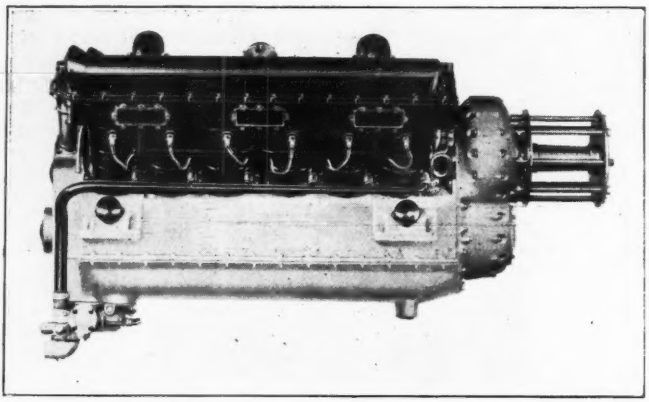


FIG. 1.—*Packard* 800 *h.p. engine.*

The most interesting feature of the design, however, is the arrangement of the ports when viewed from above. It will be noticed that the exhaust port is common for two cylinders, as is the case with the inlet ports for cylinders 2—3 and 4—5. This unorthodox arrangement makes possible a very close coupled engine, the distance from the interior of one cylinder bore to the interior of the next being only $\frac{3}{8}$ of an inch. This construction would seem to be open to severe criticism on account of the blast from the exhaust valves located in the deepest part of the pockets passing around the stems and guides of the valves near the port openings. That this design shows serious cooling problems is shown by the ingenious system of oil cooling of the exhaust valves that has been adopted by the Packard Company. Oil is fed from the camshaft bearings into the camshaft, and thence into the base of the cam follower guides through the tappets into the ends of the exhaust valves. In the valves is inserted a tube which carries the oil to the valve head, whence it flows back up the outside of the tube to holes in the stem above the valve guide. This system has worked out exceedingly well, and quite a number of engines of this design are operating very satisfactorily with a very low weight power ratio, 1.44 pounds per brake horse-power for the bare engine, in both models.

Just before sailing I heard that a Packard 1,500 engine had just completed a 50-hour full power test, developing 605 horse-power during the entire test, at 2,500 revolutions per minute.

That this type of cylinder construction is not essential to very light weight is demonstrated by the Curtiss V-1,400, which is the lightest of all our engines, and which was designed by Mr. Arthur Nutt. This engine employs a type of cylinder construction which, while originating in England, does not seem to have been sufficiently appreciated in Europe, namely, the steel sleeve threaded into the aluminium head. This construction does not permit as close cylinder coupling as is the case in the Packard design, but it is more orthodox, and I believe less liable to trouble from gas or water leakage, or from valve trouble.

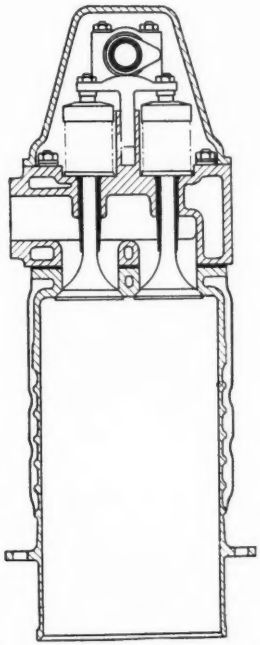


FIG. 2.—*Packard cylinder.*

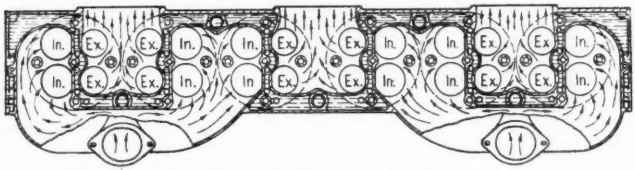


FIG. 3.—*Cross-section through Packard inlet and exhaust passages.*

It is interesting to note that the Curtiss V-1,400, which has an official rating of 500 horse-power, with a brake mean effective pressure of 134 lbs. per sq. inch, weighs only 660 lbs., or 1.32 lbs. per horse-power for the bare engine, and with high compression and special fuel, as run in the Pulitzer and Schneider Cup Races, developed 620 horse-power at a weight-power ratio of only 1.06 lbs. per horse-power.

A somewhat similar cylinder construction is used in the Wright-Tornado engine. In this cylinder the head is roof shaped and the cylinder barrel does

Rated Horse-Power.	Name.	Type.	Cooling.	No. of Cylinders.	Bore and Stroke. Inches.	Displacement. Cu. Inches.	Speed. R.P.M.	Compression Ratio.	Brake Mean Effective Pressure.	Bare Engine Weight. Pounds.	Power Plant Weight. H.P. in Pounds.
430	Curtiss D-12 ...	60-degree V Type	Water	12	4.500 × 6.000	1,125	2,250	5.3	132	690	2.20
500	Curtiss V-1400 ...	60-degree V Type	Water	12	4.875 × 6.250	1,400	2,100	5.6	134	660	1.92
420	Standard Liberty ...	45-degree V Type	Water	12	5.000 × 7.000	1,650	1,700	5.40	118	880	2.69
510	Packard 1A-1500 ...	60-degree V Type	Water	12	5.375 × 5.500	1,497	2,100	5.50	128	735	2.04
600	Wright T-3 A ...	60-degree V Type	Water	12	5.750 × 6.250	1,947	2,000	5.40	122	1,150	2.51
800	Packard 2500 ...	60-degree V Type	Water	12	6.375 × 6.500	2,489	2,000	5.70	127	1,150	2.04
200	Wright J-4 A ...	Fixed Radial ...	Air	9	4.500 × 5.500	786	1,800	5.00	112	470	2.35
350	Wright R-1200 ...	Fixed Radial ...	Air	9	5.50 × 5.50	1,176	1,900	5.0	124	640	1.83
400	Curtiss R-1454 ...	Fixed Radial ...	Air	9	5.625 × 6.500	1,454	1,700	5.4	128	790	1.975
420	Air-Cooled Liberty...	Inverted 45-degree V Type ...	Air	12	4.625 × 7.000	1,412	1,800	5.4	132	950	2.26
425	Wright P-2 ...	Fixed Radial ...	Air	9	6.000 × 6.500	1,654	1,700	5.0	120	820	1.93
30	Wright - Morehouse	2 Cyl. opposed ...	Air	2	3.750 × 3.620	80	2,500	5.00	119	88	2.93

not come in direct contact with the water. This has been altered in a later design with no increase in performance, but, as can readily be imagined, with a very great decrease in weight.

The roof type of cylinder construction involves the use of interesting tool equipment. The cylinder block is placed upon the table of a heavy duty upright drill, and the machining units, consisting of a barrel, at the base of which are two movable cutters, is fed down into the cylinder. The movable cutters are operated by a cam mechanism, which imparts to them a motion corresponding to the form that it is desired to reproduce. A cylinder head is finished in about thirty minutes.

To accommodate four valves with a single camshaft, operated by means of rockers, it was believed that a more rigid head could be produced of the roof

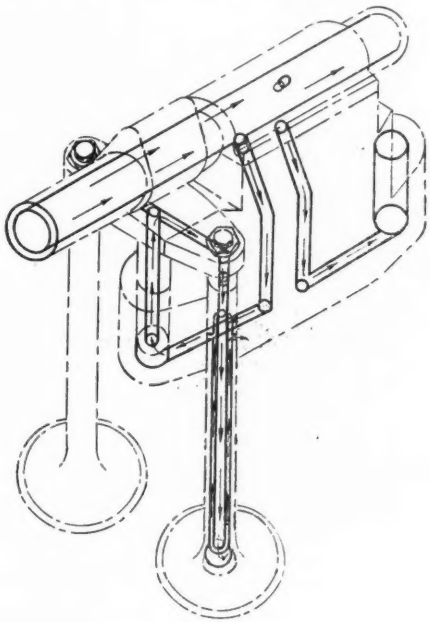


FIG. 4.

shape than was the case with the flat head employed in other American engines. For the maximum speeds at which this engine operates, around 2,200 revolutions per minute, at which speed it develops over 700 horse-power, the rocker valve gear seems perfectly satisfactory and is more compact than any of the other gears, except the Packard, which has a very convenient arrangement of the valves for operation purposes.

It will be readily understood that, with such close cylinder spacing, all these engines run to very high unit bearing loads, and it is only through the general rigidity of construction of the crankcases, bearing caps and crankshafts that such loads are possible. The crankcases are heavily ribbed, in some cases with a double rib for each bearing. The bearing caps are dural forgings of the most massive construction and the crankshafts are of very large diameter.

An idea of the relation between cylinder volume and section modulus is given in the appended table.

CRANKSHAFT DATA.

Make and Model of Engine.	Piston Displacement per Cylinder. Cu. Inches.	Main Bearing. O.D.	Main Bearing. I.D.	Polar Section. Modulus. Zp. in 3.	$\frac{Zp.}{\text{Piston Displ.}}$	Overall Length of Crankshaft. L.	$\frac{Zp.}{L \times \text{Piston Displ.}}$
Liberty	137.5	2.625	1.375	3.28in.^{3}	.0238	$57\frac{3}{4}$	.000412
Packard 1500 ...	124.8	3.000	2.250	3.62	.0290	$53\frac{7}{32}$	.000545
Curtiss D-12 ...	95.4	3.000	2.250	3.62	.0380	$49\frac{29}{32}$	.000761
Curtiss V-1400 ...	116.7	3.000	2.250	3.62	.0311	$51\frac{23}{64}$	.000605
Wright-Tornado ...	162.3	3.250	1.667	6.25	.0385	59.609	.000646
Packard 2500 ...	207.5	3.500	2.469	6.32	.0305	66.00	.000462

It will be noted how much progress in rigidity has been made since the Liberty was designed, the ratio of volume to section modulus being about 25 per cent. less than the average of the other engines.

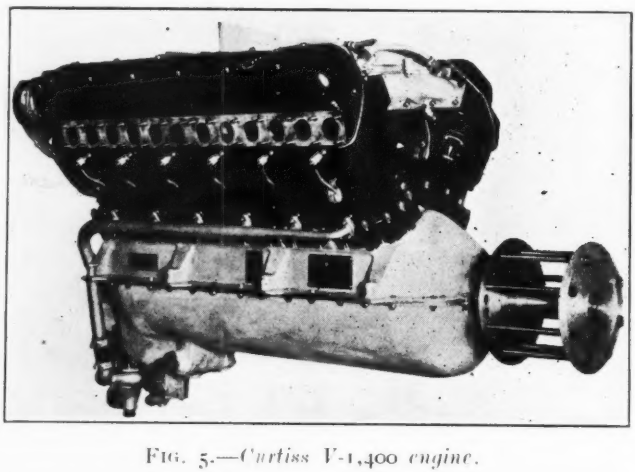


FIG. 5.—*Curtiss V-1,400 engine.*

The bearings in all the engines, except the Liberty, are steel backed, and babbitted with a metal having approximately 91 per cent. tin, 4.5 per cent. antimony and 4.5 per cent. copper. The loads carried are high and the rubbing factor in many cases becomes out of all proportion to what we have learned to believe was correct. The following table shows this clearly. In this table *PV* is the product of mean unit load by the rubbing velocity in feet per second.

It will be noted that the rubbing factor for the centre bearing of the Liberty is 22650. Formerly this was considered high, and is in fact the maximum to which this bearing can safely be subjected. On the other hand, we note rubbing factors as high as 35,000 for one of the other engines, with no apparent reason why the factor should not be still further increased. It would seem that we are far from reaching the limit in rubbing factor for oil lubricated bearings. So long as the bearing can be kept cool by a proper application of oil, or otherwise, and the parts made sufficiently rigid, it is hard to predict how far we can go in regard to bearing loads and rubbing factors. Wherever distortion takes place, localised high bearing pressures occur, in some cases stressing the bearing material beyond the elastic limit, and in any case fatiguing the metal by the

repeated deflections over a period of time. Given sufficient rigidity, the practical limit, therefore, becomes the amount of oil that can be circulated without running into oil consumption troubles. Actually the engines in question are running with oil pressures of from 100 to 160 pounds and with oil consumptions of less than 0.03 pounds per horse-power hour.

		Crankpin.			Centre Bearing.			Intermediate.		
	Revs. per min.	Maximum Unit Load.	Mean Unit Load.	P V.	Maximum Unit Load.	Mean Unit Load.	P V	Maximum Unit Load.	Mean Unit Load.	P V
Curtiss D-12 ...	2400	1230	948	24800	1190	936	29400	1053	651	20500
Curtiss V-1400										
Packard 1500 ...	2100	1191	808	18520	1692	1274	35000	1685	983	27000
Liberty ...	1700	1035	750	13200	1580	1365	22650	1150	720	1400
Wright-Tornado	2000	1705	900	23600	781	552	15700	1675	861	24450
Packard 2500...										

Articulated and forked type rods are both successfully used, but until the steel backed type of bearing, as used in the Rolls-Royce, was adopted, the advantage was all on the side of the articulated type. Without the steel backed bearings it was impossible, in large engines employing the forked construction, to get the proper big end rigidity. A few ounces saved in this part of the engine is of no consequence as compared with the gain in bearing life, and which ever type of rod construction is adopted, any weight in the big end which is properly located so as to give added rigidity to the bearing, is more than repaid in added revolutions per minute possible and in greatly increased endurance. In this connection, a process has been developed by the Allison Engineering Company of Indianapolis, whereby a bronze covering is cast upon the portion of the steel shell, which acts as a bearing for the blade rod. It adheres perfectly and can be made of any good bearing material. A high lead bronze seems the most satisfactory material for this purpose.

With the articulated type of rod, it is certain that the pistons attached to articulated rods are subjected to greater lateral unit pressures than those attached to the master rods. As we have found from our air-cooled engine development, where piston conditions are more severe and which I shall touch upon later, there is a definite limit to the unit lateral pressure which can be applied to a piston before excessive wear or scoring ensues, and therefore it seems reasonable to assume that if the articulated rod pistons run satisfactorily, then by using the forked construction the rod stroke ratio could be somewhat reduced and the engine correspondingly lightened. However, general practice in the United States seems to lean toward the articulated rod construction, all the engines mentioned, with the exception of the Wright-Tornado and the Liberty, having this style of rods.

The design of pistons in the United States seems to be somewhat stabilised, all manufacturers using some form of ribbed pistons and all, with the exception of Curtiss, using the type where the ribs are parallel and perpendicular to the piston pin axis. This type of piston will be recognised as almost the same as the original Hispano piston, developed in 1914, with the addition of a very heavy fillet on the rib over the piston pin bosses. Without heavy fillets at this point the piston is unsatisfactory, as the piston pin bosses tend to split, on account of deflection of the boss on each side of the supporting rib.

This type of piston was given up for a long time on account of the influence of the Liberty type of piston, which was being produced in large quantities during

the War. Being almost entirely without ribs, this type was very easy to cast in a metal mould, and was at that time considered the best type for the dissipation of heat down the sides of the piston and into the cylinder walls. It was unduly heavy, however, and its design did not take into account the possibilities of heat dissipation from the inside of the head to the oil which was thrown against the piston. We now believe that this method of piston cooling is just as important as the transmission of heat down the sides of the piston and into the cylinder walls, and experiments recently made with a single ring piston lead us to believe that the dissipation of heat through the piston rings, where the heat has to travel through two oil films, has been greatly overrated.

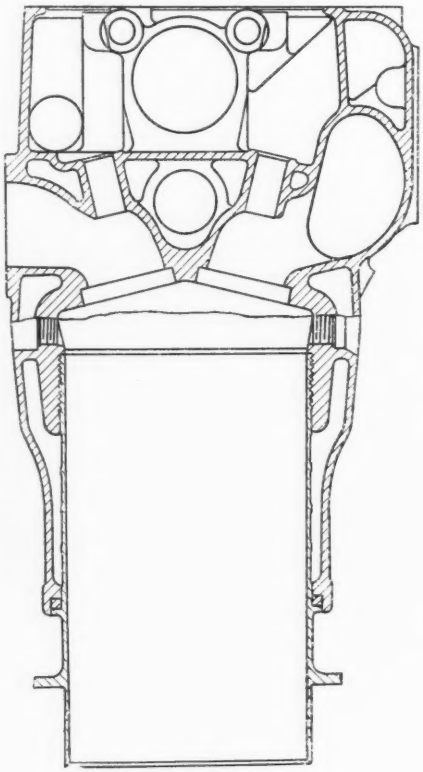


FIG. 6.—*Wright cylinder.*

The Curtiss type of piston is different, having radiating ribs and a circular rib in the centre and, although the design seems to me less logical than the type described above, the results are eminently satisfactory.

An extreme type of piston, which has proven very satisfactory for use in water-cooled engines, is the Packard piston. This is of the slipper type with a heavy and essentially ribless crown. Some idea of the extreme dimensions of this piston may be gathered from the following table:—

	Diameter.	Total height.	Weight, bare.
Packard 1500 ...	$5\frac{3}{8}$ in.	$3^{11}/_{32}$ in.	2.04 pounds
Packard 2500 ...	$6\frac{3}{8}$ in.	$3^{15}/_{16}$ in.	4.47 pounds

The length of the 1500 piston is only two inches below the rings.

Going to the opposite extreme is the piston of the air-cooled Liberty engine, in which it was desired to keep the engine unchanged and retain the old camshaft centres, merely substituting new cylinders. This necessitated locating the piston pin in the bottom of the piston. The bearing surface is very large and the great success of this engine is in part due to this unusual piston, which runs cooler and remains in better condition than any aircraft piston I know of, whether air or water-cooled. The material most favoured for pistons in the United States is the "Y" alloy originally developed by your National Physical Laboratory, with a composition of

Aluminium	92½	per cent.
Copper	4	,,
Nickel	2	,,
Manganese	1½	,,

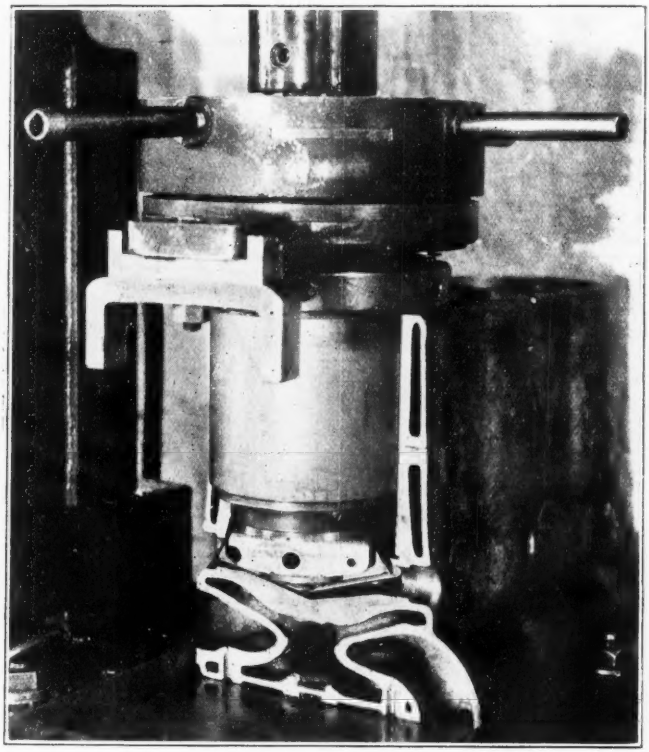


FIG. 7.—*Cylinder-doming tool.*

This material is treated at 935-965 degrees Fahrenheit for five hours, quenched in boiling water, aged one hour at 400 degrees Fahrenheit, and should have a Brinnel hardness of 100 minimum when sand cast, and somewhat higher if die cast. The tensile strength should show a minimum of 33,000 pounds per square inch.

Several types of American engines are now being built for use inverted.

The water-cooled Liberty was the first on which this modification was made and proved very satisfactory from a service standpoint, on account of the greater accessibility of the most important parts as well as on account of the greater vision afforded the pilot in the direct line of flight. From an aerodynamic standpoint the high centre of thrust which is easily attained, overcomes the tendency of the airplane to climb when full power is on and allows greater propeller clearance than could otherwise be obtained. The low position of the carburettors frequently allows a gravity fuel installation with many obvious advantages.

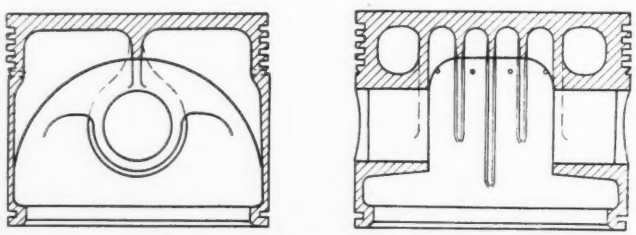


FIG. 8.—*Wright ribbed piston.*

Some ships, such as the Loening Amphibian, which have been designed around this type of engine, have given very satisfactory results, and the air-cooled Liberty, of which more will be said later, is also designed to be used in an inverted position.

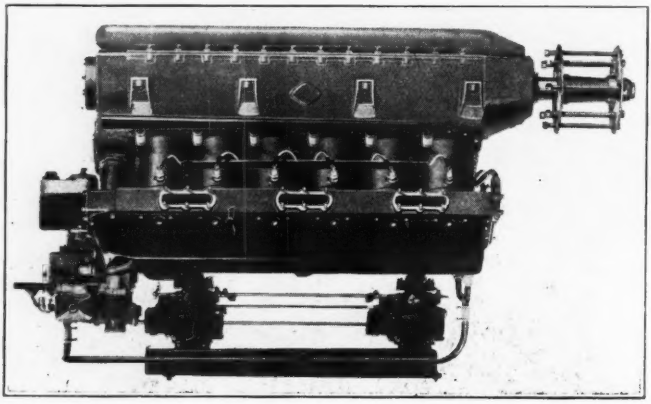


FIG. 9.—*Packard inverted 500 h.p. engine.*

One of the details of aircraft engines in which we have been most backward in the United States, in my opinion, is the matter of reduction gearing. Until very recently practically all engines were built with the direct drive, in spite of the fact that a very satisfactory reduction gear, with a spring coupling, had been developed for some time by the Allison Engineering Company, of Indianapolis. At present practically all the new projects for aircraft engines, except those used for pursuit or training purposes, provide for the installation of reduction gears, and practically every type of reduction gear is being studied or developed by one manufacturer or another.

Turning to air-cooled engine development. The Wright Whirlwind, 9-cylin-

der air-cooled engine, of 200 horse-power, is the only air-cooled engine in quantity production in the United States, although several larger models are in process of development and will, I believe, shortly be produced in quantity. I shall touch upon this later. About 600 Whirlwind engines have now been manufactured and are being generally adopted for commercial service, especially in three-motored passenger planes. The popularity of this engine to-day, and its availability for commercial aviation, are largely due to the far-sighted attitude of the Bureau of Aeronautics of the United States Navy. Realising the ultimate possibilities of this type of engine, they decided to make air-cooled engines standard equipment for all power plants up to 300 horse-power. This in spite of the fact that the Hispano type water-cooled engine that had formerly been used for this purpose was a very reliable engine.

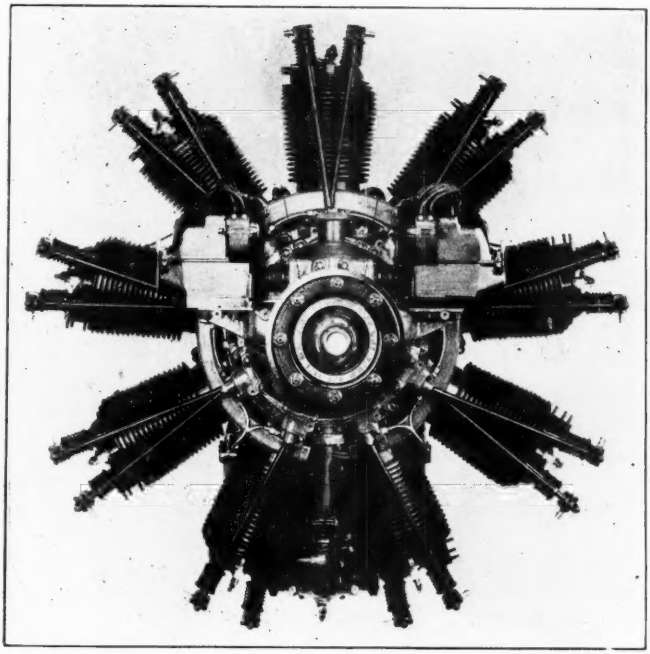


FIG. 10.—*Wright J-4a engine.*

Through the use of a large number of units under service conditions it became possible to eliminate all causes of failure, and it stands to-day as one of the most reliable power plants that I know of. The cylinder is of aluminium construction, shrunk and threaded on to a steel sleeve, the holding down flange being integral with the sleeve. This construction is less costly than the method of forming the cooling fins in the steel barrel. Comparative tests made by us show so little difference in cooling as to be negligible. However, for larger engines, this construction is somewhat heavier than the steel fin type of cylinder, and the shorter aluminium head makes possible the setting of the valves at a greater angle to the cylinder axis, without the boring bar striking the cylinder walls and permits of better cooling of the exhaust port.

The position of the magnetos is somewhat unusual, but has much to commend it, especially on small engines, where the space back of the engine is rather

restricted. On larger models, where the bolt circle for mounting is larger, the advantage of this position is less pronounced. With proper cowling design the magnetos can be given adequate protection in front and not interfere with the clean design of the airplane.

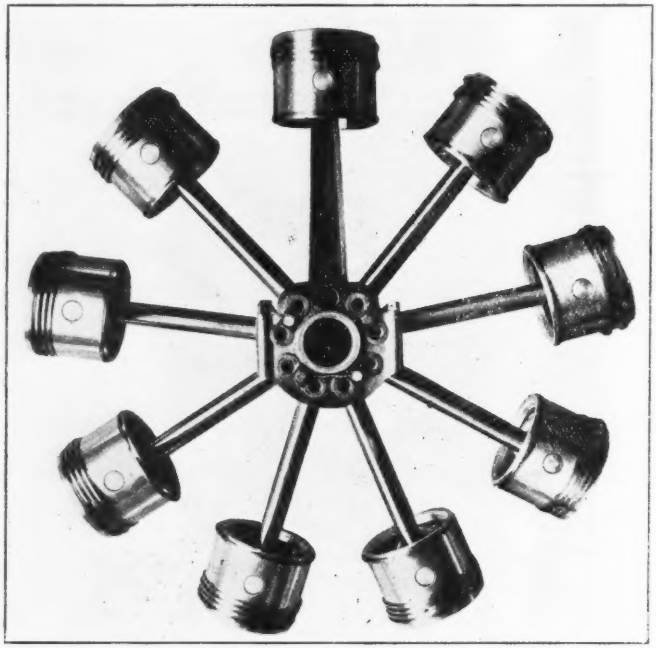


FIG. 11.—*Wright J-4 rod and piston assembly.*

The master and link rods are of very sturdy construction, and the heavy section in the big end is responsible for the very excellent bearing conditions that prevail in this engine.

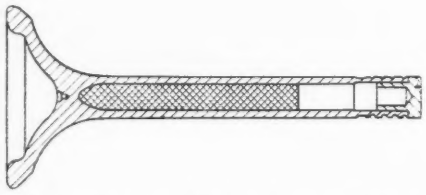


FIG. 12.—*Valve with stem filled with potassium nitrate and sodium nitrate.*

The limit of bearing loads and rubbing velocities has nowhere nearly been reached, but at the end of a full power run of 50 hours, at 2,000 revolutions per minute, the bearing showed practically no wear. A 50-hour test at 2,200 revolutions per minute will be attempted shortly.

The induction system consists of three circular passages placed side by side, each one supplying three cylinders. These are joined by a manifold and connected to a double carburettor with a float chamber located between the two venturis, so as to maintain a constant level in all flying positions of the airplane. Somewhat higher mean effective pressure can be obtained with three separate carburettors, but the difficulty in service of maintaining the adjustment of three separate carburettor units, especially in the closed throttle position, leads us to believe that it will be worth while to design a triple venturi carburettor.

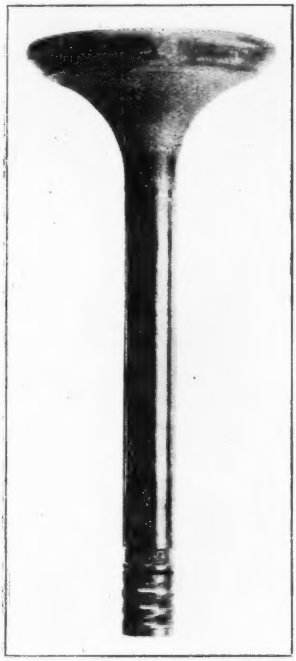


FIG. 13A.—*Salt-cooled valve after test.*

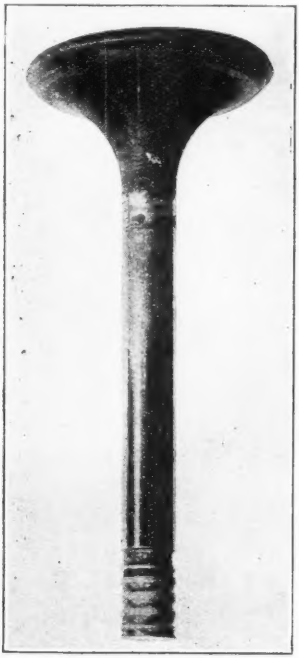


FIG. 13B.—*Valve without salt cooling.*

As can be imagined, in a power plant rated at 200 horse-power and of very sturdy construction, the weight per horse-power will be somewhat high. In this case the weight is 465 pounds, or a ratio of 2.34 pounds per horse-power, which, nevertheless, compares favourably with water-cooled engines of the same power, when the water and radiator are taken into account.

It would be impossible to cover the field of air-cooled engine development properly without touching on the work of Messrs. S. D. Heron, one of your compatriots, and E. T. Jones, both formerly of the Power Plant Section of the United States Army Experimental Station, at McCook Field, Dayton, Ohio, and now engineers with the Wright Aeronautical Corporation. These men have carried on a series of single cylinder air-cooled engine tests, following up the work done during the war at Farnborough, in which Mr. Heron assisted. Much of this work has been published. So I shall touch on only a few points.

The most unsatisfactory detail of the air-cooled engine has been the exhaust valve and guide which, with conventional design, would not last more than about 25 hours at full power, in a cylinder developing 48 horse-power. The valves ran red at the junction of the stem and neck and finally failed at that point. The guides quickly wore out. A form of construction was developed with a file-hard tungsten valve, having a seat diameter of 2¼ inches and partly filled with salt, consisting of 45 per cent. sodium nitrate and 55 per cent. potassium nitrate (by weight), and running in a hard tungsten steel guide. The valve cooling was much improved and the hot zone was greatly reduced in area. After 100 hours of full power running, the last 50 hours being purposely under conditions of violent auto ignition, scaling on the neck of the valve was evident, but very little was observed on the stem. In the view on the right of the slide the condition of the valve after the test will be observed. The valve on the left is an unfilled valve after a 50-hour test. Due to a roller having been installed on the rocker tappet, wear on the tungsten valve guide was eliminated, although running entirely without lubrication.

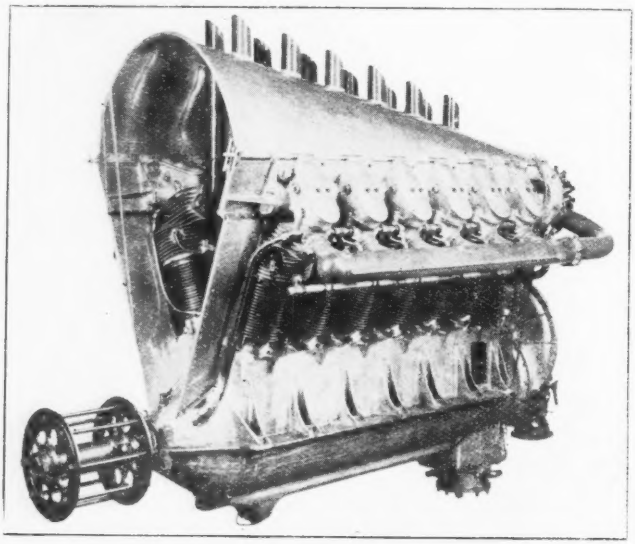


FIG. 14.—*Air-cooled Liberty engine.*

These and other experiments in air-cooled exhaust valves have been very valuable, not only for air-cooled, but also for water-cooled engines, which often run considerably hotter than the valves referred to above. A practical application of the foregoing has occurred in the servicing by the Wright Aeronautical Corporation of a large number of unused Model E, 200 horse-power Hispano engines, built by our company during the War. With slight modifications the exhaust valves are salt filled, giving the engines a life between overhauls three times as long as before.

Another interesting development has been carried on around a smaller cylinder of 4½ inches bore. One of these was made up of cast iron with surprising results. The cylinder developed 140 brake mean effective pressure, or 27.8 brake horse-power, at 1,800 revolutions per minute. The temperature of the head at a point on the exhaust valve seat reached as high as 750 degrees Fahrenheit.

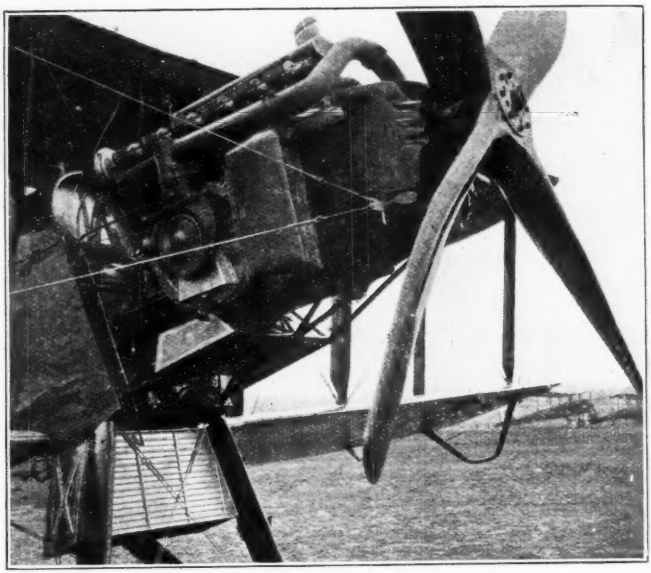


FIG. 15.

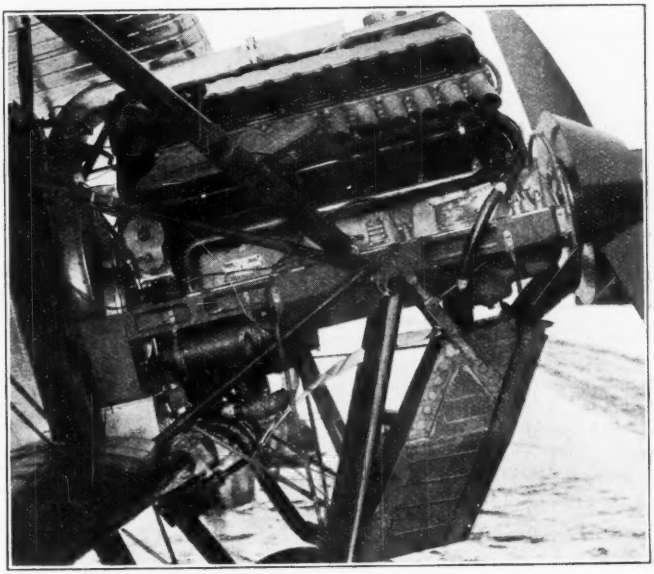


FIG. 16.

Despite the high head temperature, excellent cooling was obtained with the salt-cooled valve, the hottest zone being in the middle of the neck about $\frac{3}{8}$ of an inch wide and just perceptibly red.

At the conclusion of these tests the fins were removed from the cylinder and head and a water jacket welded in place. No difference in performance whatever was noted, but the valve cooling was somewhat improved, the valve running dead black. The cooling of this cylinder and valve, in either its air or water-cooled form, is the best example of valve cooling of which I have any knowledge.

One of the most interesting developments of recent years is the air-cooled Liberty, referred to earlier in this paper, and developed by Messrs. Jones and Heron. This is a most satisfactory power plant, developing 420 horse-power at 1,800 revolutions per minute, but necessarily somewhat heavier than would be the case if it were a completely new design and not an adaptation, but nevertheless 200 pounds lighter than the water-cooled Liberty with radiator and water.

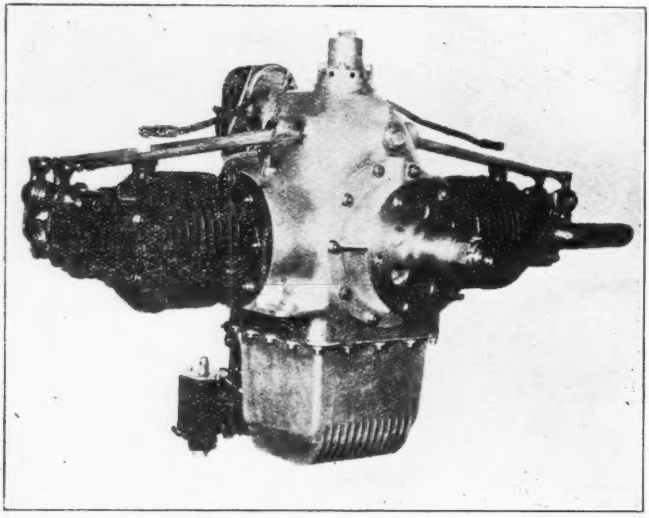


FIG. 17.—*Wright-Morehouse light plane engine.*

As 10,000 new Liberty engines are still in storage, and as the water jackets are beginning to corrode and become unreliable, the importance of this development from a commercial and economic viewpoint, as well as for its military value, is quite evident.

In order to obtain sufficient space between the cylinders for proper air cooling, it was found necessary to reduce the cylinder bore to 4.625 inches instead of 5 inches as formerly, and to get the power by higher mean effective pressure and higher revolutions. With the water-cooled Liberty 1,700 revolutions per minute was the highest speed at which the engine could run satisfactorily, but with the lighter reciprocating parts and smaller piston areas of the air-cooled engine, speeds of 1,800 revolutions per minute are satisfactorily maintained.

Barring a few minor changes, the rest of the engine, except the cylinders, valve gear, pistons and induction system, remains the same.

The cooling is obtained by means of a scoop, as in some of the early English and French air-cooled V-type engines, which provides easy means of shuttering

in cold weather. The distribution of cooling air to the various cylinders is much less troublesome than was anticipated, no baffles or deflectors being necessary.

An interesting and novel feature of this engine is the installation of a built in, gear driven, low altitude supercharger, which adds practically nothing to the weight of the engine. A similar supercharger, installed in a Curtiss D-12 engine, added only five pounds to the weight of the engine, on account of the quantity of parts that it replaced. As at present installed, this supercharger is nothing more than a rotary induction system, somewhat similar to the one used in your Armstrong-Siddeley engines, and from the point of view of distribution alone it

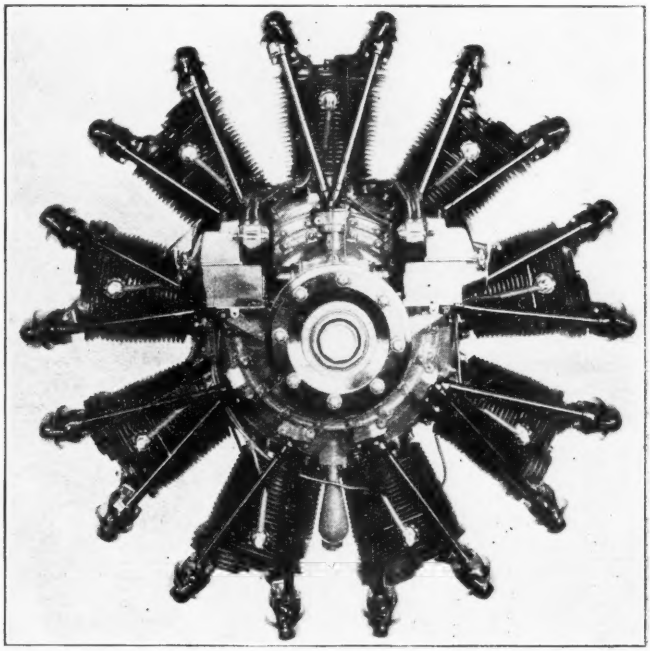


FIG. 18.—*Wright R-1,200 engine.*

is a very useful device. We believe that it will be possible to supercharge to altitudes of perhaps 10,000 feet, but so far we have only tested it in the air under conditions where a manifold pressure of two or three inches of mercury was obtained. The value of this type of supercharger, therefore, is as yet to be determined.

The foregoing, of course, refers to superchargers built as an integral part of the engine. This general problem of supercharging has received a great deal of attention and some highly satisfactory results have been obtained. The turbo and centrifugal types have been investigated by the Engineering Division of the Air Service, co-operating with the General Electric Company, while the Roots type has been studied by the Navy Department in co-operation with the National Advisory Committee for Aeronautics.

The General Electric turbo supercharger has been developed into a highly reliable and satisfactory piece of equipment. This supercharger is designed for application to engines of the 400-500 horse-power class and has a nominal rating

of 20,000 feet. However, by overspeeding, sea-level pressure may be maintained at the carburettors up to altitudes of 30,000 feet. In principle this supercharger follows the lines originally established by Rateau, but in the matter of arrangement and mechanical detail, it departs entirely from the Rateau design. The supercharger is located at the side of the engine, with the turbine on the exposed side for cooling. The compressor is located between the turbine and the engine, and the compressed air passes from the compressor through an air cooler to the front of the engine, thence into the Vee to the carburettor inlets. The air cooler is located directly in front of the supercharger, thus keeping the total projected area to a minimum. This type of supercharger is definitely past the experimental stage and is considered as a standard piece of service equipment.

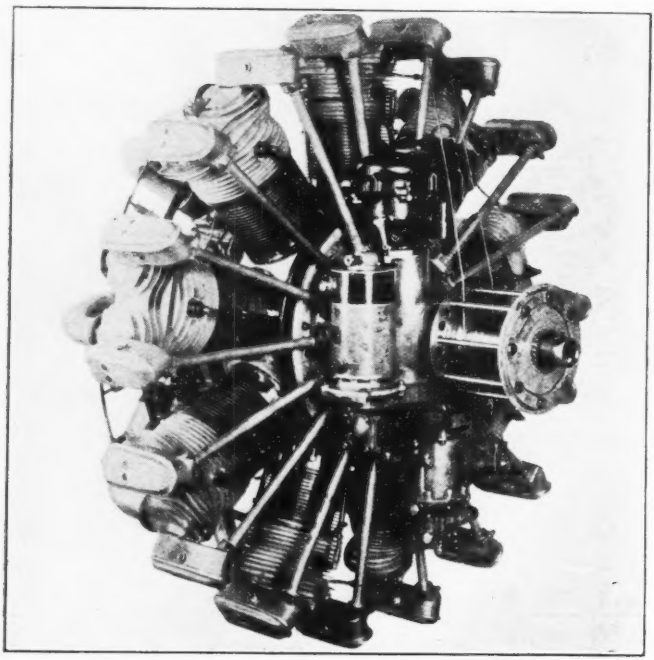


FIG. 19.—*Curtiss radial engine.*

Experiments with the geared centrifugal supercharger have been largely devoted to the development of a reliable driving train. While a thoroughly reliable and satisfactory design has not yet been developed, some very encouraging results have been obtained, and those directly connected with the development are confident that the difficulties will eventually be overcome. This type of supercharger will probably be developed with a moderate altitude rating (say 10,000 feet), having the carburettor on the suction side of the compressor. The turbo type will continue to be used for very high altitudes.

The development of the Roots' type supercharger by the National Advisory Committee has been highly successful. A compact, reliable and rugged design has been developed, and this type promises to compete with the turbo type for altitude ratings of 20,000 feet and up. This type possesses the advantages of mechanical simplicity and ease of control and, due to its moderate speed, the

gearing and drive mechanism appear to offer no serious difficulties. The fact that this type does not lend itself to the arrangement with the carburettor on the suction side of the compressor would seem to give the centrifugal type the advantage for moderate altitude work.

The only light plane engine in production in the United States is the Wright-Morehouse engine designed by H. E. Morehouse and now manufactured by the Wright Aeronautical Corporation. This little engine is a two-cylinder engine of a type much more familiar to the British and French airplane industry than to our constructors in America. It has a cylinder volume of 80 cubic inches, which is the standard in the United States for light plane engines, and has been designed for low cost production in quantities as much as for high performance. For this reason cast iron cylinders have been employed, with a rather flat head, with some sacrifice of cooling qualities in favour of cheap production so as to be

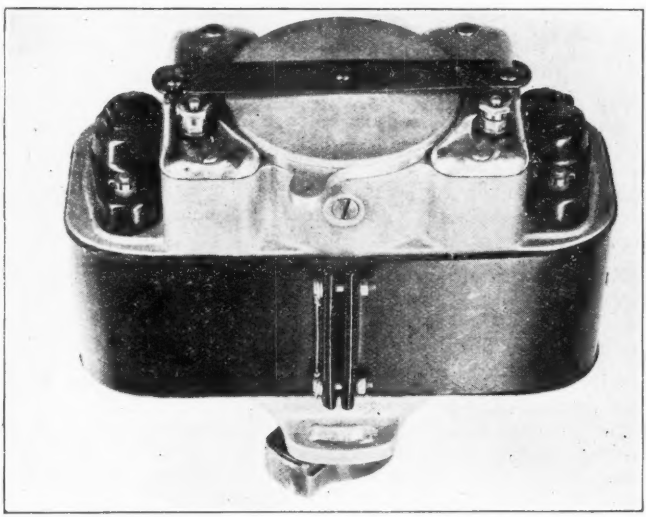


FIG. 20.—*Splitdorf double magneto.*

in reach of as many users as possible. Nevertheless, its performance is very creditable, brake mean effective pressures of 117 being easily obtained. The connecting rods are duralumin forgings, babbitted directly on the duralumin. Ignition is obtained from a single two-cylinder magneto. In spite of the cast iron cylinders, the weight is not excessive, being only 88 pounds, and the horse-power developed is 30 horse-power at 2,500 revolutions per minute, giving a weight power ratio of 2.93 pounds.

There are three large radial engines being developed in the United States at the present time with satisfactory results. They are the Wright-Simoon, an engine of 1,200 cubic inches, developing 350 horse-power, which has just completed a full power 50-hour test at 1,800 revolutions per minute; a Curtiss Radial, of 1,454 cubic inches and 400 horse-power, is now undergoing acceptance tests at McCook Field, and is almost ready to be put into production; the Wright-Cyclone, a 425 horse-power engine, of 1,657 cubic inches, with a bore of six inches and a stroke of 6½ inches, is now undergoing acceptance tests for the United States Navy.

The enclosed valve gear will be noted in all these engines, due to the belief that the operating parts should be properly lubricated and the valve springs protected from spray when used in seaplane installations.

Failure of exhaust valve springs has often resulted from the sudden chilling due to spray from the floats or propeller. Another important reason for the enclosed valve gear is the ease with which an enclosed valve gear lends itself to compensation, a very important item if durability is a consideration. Wind tunnel experiments have shown that the gear on the top of an air-cooled cylinder offers considerable resistance and the gain in head resistance by enclosing these parts in streamlined boxes is by no means negligible.

As these last three engines are still in the development stage, I do not feel at liberty to give out any detailed information with regard to their design, but believe that the photographs which I am showing will be of interest.

Another interesting development being carried on in the United States is the double magneto. In its latest form this consists of a magneto with a double armature winding, but having two separate breakers and independently driven distributors. Until recently there has been a very strong feeling against any system except complete dual battery or magneto apparatus on account of the possible failure of the drive as well as because of fear of failure of the apparatus itself. Successful magneto drive depends largely on lack of crankshaft vibration, and in our modern engines, both water-cooled and air-cooled, this trouble, at least for the speeds we now run at, seems to have been almost entirely eliminated. From a weight consideration alone the dual magneto warrants intensive study and development.

Summing up our tendencies in aircraft engine design, I should say that in the water-cooled engines we had standardised on the 12-cylinder Vee type, as close coupled as possible, of very rigid construction and with a rapid trend toward higher speeds of revolution.

In the air-cooled field we have far from reached the ultimate type, but have at least put our cylinder cooling and valve troubles behind us, and are now attacking the problems of master rod and articulated rod construction that are involved in the tendency toward higher speeds of revolution. As I stated before, the air-cooled piston is subjected to considerably higher temperatures than the piston of the water-cooled engine and, on account of the motion of the master rod, much greater angularity prevails in the connecting rods on the opposite side of the engine in a nine-cylinder engine, numbers 4, 5, 6, 7. This angularity causes greater side pressure on these pistons and the master rod piston also is subjected to special side pressure, due to the action of the other cylinders upon the rod. All these conditions must be met by a balanced design, which will maintain the outside diameter within as small limits as possible and yet provide satisfactory conditions for the operation of the parts just mentioned. The big end of the master rod must be given sufficient stiffness to permit of higher rotative speeds than are used at present. In fact, there are a number of problems still to be solved before the air-cooled radial will become as standardised as the water-cooled 12-cylinder engine.

The Vee type air-cooled engine, on the other hand, now that its cylinder and valve problems are solved, can follow the general lines of water-cooled technique and will, I believe, during the next few years become a very popular type wherever overall length is not the deciding factor.

Discussion

Wing Commander Hynes: I have been caught quite unprepared so early in the proceedings in being asked by the Chairman to open the discussion. Being very closely in touch with this class of work, I should certainly like to begin by expressing our very best thanks to the author for giving us such a clear exposition of the position relating to modern American aircraft engines. It will be very helpful to those of us who are engaged in this work because all sorts of rumours get about and it is sometimes very difficult to sort out what is true and what is untrue. Therefore, to receive a first-hand statement of what is the actual position is of extraordinary interest. As a matter of fact, so far as the paper is concerned, I do not feel that there is a very great deal one can discuss. It contains a great deal of information and it is difficult to discuss it without entering into matters of technical detail. At the same time I do not mean that we should not like to ask the author to spend a whole evening here answering questions, but strictly as regards the paper itself, I feel that it is rather difficult to discuss. There are, however, two or three matters upon which I should like some further information, if the author can give it. The first point is that he showed us a picture of an air-cooled Liberty engine with an overhead camshaft, and that struck me as a very interesting piece of work because it has always been considered difficult to run an engine of that type with an overhead camshaft owing to the relatively large expansion of the cylinders which is possibly not always equal. It would be interesting to know whether any troubles of that kind have been experienced with this particular engine, and if so, we should like to know how the trouble has been got round. Then there is a point which seems to me of great interest in connection with the statements in the paper concerning the development of gears on American engines. That is a very interesting matter because I think there is a great deal of misapprehension as regards the mere weight of engines as a result of incorporating gears. The ordinary direct drive engine, of course, is bound to be lighter than the geared engine of the same type. I feel that the author has started a very useful line of thought in speaking of the power plant weight per h.p. hour. That, it seems to me, is a very great advance because just the bare dry weight of the engine is not alone a sufficient criterion. As a matter of fact, I would suggest that it is even worth while considering whether we cannot go one farther and talk of the power plant weight per thrust h.p. hour for given conditions. That takes into account the airscrew efficiency because it is not only conceivable but possible, especially in the case of high-speed engines, that by adding the gear, which increases the weight but slightly, one can increase the airscrew performance in the low-speed machine, such as the commercial machine, and so in effect increase the engine performance in overall efficiency. From this point of view it is interesting to hear that the production of geared engines in quantity is under consideration in America. A reference has been made to the Roots' supercharger, which is placed in front of the carburettor. Could the author tell us anything about the arrangements made for pressure balance? You have the carburettor under pressure and that means putting the petrol system in some way under pressure. How do they overcome that and is it entirely reliable?

Mr. Thomas: I think we have to congratulate the author on the extremely interesting and valuable paper which he has read, but there are a few points on which more information would be valuable, and which would greatly add to the interest of the paper.

For instance, the weight assumed to cover the radiator and water pipes, etc., is given as 0.6 lbs./h.p. Looking at the data given in the table, it appears that, with one exception, all the water-cooled engines are of the high-speed direct drive type, and would, presumably, be fitted to high-

speed aeroplanes. If this is the case, then while 0.6 lbs./h.p. would probably be correct for aeroplanes of moderate speeds, it would seem that it is too high for the machines in which these engines would be installed. If the author could give us the actual weight of the water installation for one of these machines, it would be of great assistance.

Again, in comparing the water- and air-cooled engines, I do not think the author has gone far enough to enable us to arrive at a conclusion on the merits of the two types of engine. I think that the weight of the fuel and oil tanks, with pipes, and the weight of fuel and oil for one, two or three hours should be included in the data given, and if the author could add this information to the paper, it would place the two types of engine on a more suitable basis for comparison.

Major T. M. BARLOW: As a member of a British aircraft firm with a live practical interest in American aircraft engines, I should like to express my appreciation of this paper. Without wishing to start any controversy, I think we must all agree that American aircraft engine research has developed at a very rapid rate since the end of the war, and it has certainly reached a stage when we in England can learn something from that development. Whether we copy or use that information is up to us. I hope at some later date we shall be treated to a paper in which the lecturer will go into a little more detail as regards engine construction, because I am firmly convinced that the efficiency and reliability of American engines depend to a considerable extent on the material they use. There are one or two points I should like to draw attention to with regard to the engine data table. The first is that the Curtiss D-12 engine with a 6 to 1 compression ratio has a British rating of 430 h.p. at 2,100 r.p.m. on standard British fuel. Perhaps the author may be under a misapprehension as to the benzol content of that fuel. It is really 20 per cent. benzol added to the standard aviation fuel which already contains a certain percentage of aromatics, whereas I understand that the American mixture is a straight spirit plus benzol.

The AUTHOR: There is no benzol.

Major T. M. BARLOW: Another point in connection with the same engine is the high m.e.p., 140 lbs. per sq. inch, at normal r.p.m. That is a remarkably high figure for a service engine. There are two features of the paper to which we in England should pay special attention. The first is the predominance which is being given in America to research on supercharging, very successfully from all accounts, and also the development of the air-cooled inverted type of engine. The aircraft designer will, I am sure, appreciate this latest type of engine, for it gives quite a small frontal area and allows an excellent view for the pilot. Moreover, in the case of service aircraft, this type of engine allows the easy installation of guns for firing forward through the propeller.

Colonel BRISTOW: The figures given of the high bearing loadings worked to in America are interesting, but are confirmed to some extent by work that has recently been carried out in this country. With the same material as the author has shown running on the big end of the Wright T-3 we have run for many months at a *PV* figure of 32,000 and at an oil pressure of only 60 lbs. If I may ask the author one or two questions I should like to know whether they expect to experience the greater difficulty in making a propeller shaft reduction gear that will stand up to the engine or an engine that will stand up to the gear. When I was working at Dayton for a short time there was a reduction gear that worked quite satisfactorily on the Liberty engine, but no Liberty engine could stand up to the gear.

Experience seems to show that the reaction of the gear on the engine is a most important factor in regard to the overall reliability and that the production of a good type of gear is by no means the end of the matter. I should also

like to know how in America the type of fuel available is made to keep pace with engine development. Over here every step towards increasing the volumetric efficiency is accompanied by an ever greater difficulty in securing suitable fuels, and the position here has become so acute that if war occurred and anything happened to restrict the free supply of benzol, the position of the Air Force would be extremely serious.

Another point I think many of us would be interested to know about is the relative severity of the American and British type tests. I should specially like to know whether American air-cooled engines when undergoing their type test with propeller are cooled by any additional blast or whether the propeller blast is sufficient. The ability of an engine to keep cool under the latter condition is of course most important, especially when considering an air-cooled type for seaplane work.

I noticed also that in the photograph of the Liberty air-cooled engine the exhaust pipes had been changed over from the outside of the cylinder to the V side under the cowling and should like to know the reason for this step as at first sight it would appear that the original reverse position would have been preferable.

Mr. FEDDEN: I have listened with very much interest to Mr. Lawrance's most entertaining lecture on aero engine development in America, and wish to thank him very much indeed for his most excellent survey of the work done during the last few years on aero engines in that country. I should like to raise the following points on his paper, viz. :—

First, with regard to the very interesting table at the beginning of the paper, in which some of the figures are really most remarkable, there is a question which Colonel Bristow has just raised, viz., that in order to make a fair comparison of this table with our own aircraft engine development, it is necessary to know how the American type test, to which their engines are submitted before going into production, compares with the type test in England. We in this country have found a very great difference between our old 50 hours' type test and the new 100 hours' type test.

Referring to the tabulation of crankshaft and bearing pressures, the figures for bearing pressures are especially interesting, and I quite agree with Mr. Lawrance we have not yet arrived at the limit of bearing loads. The stiffness of the crankshaft and the crankcase generally is of the utmost importance in determining the limit of bearing loads. I do not think we in this country have approached the *PV* figures quoted by the author. On the Jupiter engine the corresponding figures for this table are :—*PV* 14250, maximum bearing pressure 1340 lbs./sq. inch, mean bearing pressure 960 lbs./sq. inch. The author mentions that the bearings in all the engines referred to in the table are bronze with white metal babbited. I should be interested to know whether the lead bronze metal called " Sumet " or " Kelmit " is used on any production type engines, and if so what clearances are used.

In considering the oil pressures and oil consumptions it would be interesting to know the quantity of oil circulated per hour.

Referring to the author's remarks on pistons, it is curious we have not experienced the difficulties of lateral limiting pressures which he mentions, and in this connection I believe the rigidity of the parts and even distribution of the load is of immense importance. The standard Jupiter air-cooled piston $5\frac{3}{4}$in. bore, weighs 2lbs. 13ozs., the projected area of the skirt is 9.7in., the maximum bearing pressure on the thrust side is 144lbs. per square inch, the length of the piston is $3\frac{3}{8}$in. We have experienced no trouble whatsoever with this type of piston on a 400 h.p. production type air-cooled radial over 200 to 300 engines. I note with interest Mr. Lawrance says that the standard material for pistons in America is " Y " alloy. We appreciate the value of this material, but we have

not been successful in casting it in production form. I would like to know what special methods are used in America when casting "Y" alloy to get over the difficulties we have experienced. We have found in this country there is a good deal of trouble to get the nickel to alloy in the temper metal, and that "Y" alloy, although excellent as regards strength and heat conductivity, is sluggish when used for such complicated forms as a piston or air-cooled cylinder head. We are doing some interesting work in "Y" alloy forgings in this country, but we certainly have not had much success with piston castings.

I was also very interested in the author's remarks about salt cooling valves. When I saw the result of these experiments in the S.A.E. Journal of February, 1924, I immediately set to work to carry out a series of experiments, and we tried valves with salt and mercury cooling. With valves 1⅛in. I found no increase in the life of the valve with salt cooling, and only very little increase with mercury cooling, and therefore we did not think the game was "worth the candle." I presume this was due to the fact we were using comparatively small robust type valves which without the special cooling were never very hot; normal valves of this type never exceed 630°C. In connection with this matter it is interesting to note that we in this country have had no success with single exhaust valves on large air-cooled cylinders, and we are in favour of two exhaust valves at speeds above 1,600 r.p.m. with large cylinders.

I was also interested in the slide Mr. Lawrance showed us of the Splitdorf double magneto. We have considered and got as far as drawing out such a scheme in the country, but I do not think it has ever been made. I would like the author's experience generally on the reliability of magnetos on aero engines in America, as magnetos have been rather troubling us over here lately.

On one of the slides showing a Wright engine I was interested to see an aero marine inertia starter, built into the crankcase, and should be glad if Mr. Lawrance would give us some experience of this type of starter, as we are interested in it for installations where our gas starter system is too heavy. I see it is built quite neatly into the Wright engine, and it would be interesting to know whether this starter works satisfactorily in cold weather, what is the addition in weight, and whether any trouble has been experienced with torque recoil when mounting the starter on the crankcase.

Mr. A. E. PARNACOTT: I, with the other speakers, wish to thank the author for his excellent resumé of American aircraft engine practice. If one studies the publications in connection with water and air-cooling of engine during the past 10 years one must agree with the author that the evidence is in favour of the air-cooled engine particularly for aircraft for war purposes. One feature about the paper which I think is excellent is that the author has mentioned the names of the designers of the various engines; it is too often neglected. In connection with the water-cooling system where the water is circulating, it has been found in steam practice that it is better to allow the steam to pass through a small head of water rather than a large head of water; when passing through a large head of water, the steam carries water up and surging takes place.

A short time ago I inquired of the oil firms the specific heats of their oils. The oil is used very largely as a coolant for the heat generated in shearing the oil in the bearings, and I was surprised that I could get no satisfactory answer. The heat capacity of oil is about one-third the heat capacity of water, and if the pressures and rubbing velocities of plain bearings are to be put up any farther, it is worth while considering water cooling, internally, or crankshafts. According to research work by Mr. Michell, there seems to be no limit to the rubbing velocity of plain bearings if you take care to ensure that the bearing is rubbed over a considerable amount of its width. In many engines, however, owing to flexure, the bearing is only touching close to the cheek of the crankshaft, hence

the value of plastic white metal. In the paper there is mention of 134lbs. m.e.p., and if that is taken in conjunction with a statement where the author mentions the reduction gearing, I think I can make some useful comment. Personally I think it is a mistake to rate engines upon m.e.p. When you are working at high m.e.p., you have your exhaust taking place at a considerably higher pressure than when working on a lower m.e.p., and although the characteristics of internal combustion engines are different from those of steam engine practice, the same law applies: I think that rather than face the difficulties of gear reduction, it would be better to expand the gases to a larger extent and in that way have less trouble with the exhaust valves, because then there are lower temperatures and lower velocities of the gases sweeping the exhaust valves. In connection with the cooling of exhaust valves, the time element is very important and the gas velocity is very important, so that I think it behoves us in designing exhaust passages, to make them as streamline as possible. It is quite common with the guides of exhaust valves to terminate with an abrupt end and in practice the corners of these ends become intensely hot.

It is very satisfactory to find the United States getting such good results with what is essentially a British alloy, for pistons. There is, however, a large amount of success being obtained at the present time with magnesium pistons, but they must be of pure magnesium rather than alloys. It is not generally known, perhaps, that the melting temperatures of pure metals are lower than those of alloys.

The author speaks of a double carburettor with the float chamber located between two Venturis to maintain constant level. I cannot understand how this can ensure a constant level in the jets.

Colonel FELL (*contributed*): He had listened to Mr. Lawrance's paper with the greatest interest. The point which struck him most forcibly was the absolute impartiality of the author's treatment of his subject.

Colonel Fell wished to raise certain points regarding the rating of American engines. It would seem that the figure quoted for bare engine weight had not the same meaning as the term used in this country, namely, weight of engine dry. For instance, the Curtiss D-12 was given as weighing 690 lbs. whereas the engines of this type received in this country weighed from 730 to 735 lbs. Colonel Fell thought it was probable that in America they were not in the habit of including in the weight such parts as propeller hub and starting gear. He would like the author's remarks on this point.

Colonel Fell also wished to know how the horse-powers for rating purposes were determined, and whether these were taken at the maximum r.p.m. at which the engine was allowed to be run. In this country the rated horse-power was that at which the engine had done type test and at the normal r.p.m., which was 10 per cent. below the maximum.

On the remarks on cylinder construction—had any experiments been carried out on cylinder blocks in which there was no water space between the cylinders at all. This was now common practice on motor-cars and resulted in a much stiffer cylinder block when a cast aluminium structure was used.

Colonel Fell noticed throughout the paper what very much higher propeller speeds seemed to be in common use in America than in this country. For instance, the Wright Tornado, which gave 700 h.p. at 2,200 r.p.m., would have but small application with aircraft designers in this country.

Had any experiments been carried out with the floating bush construction of big end? A recent test carried out by Mr. Ricardo on his bearing testing machine run at a bearing factor of 70,000 and with a load of $7\frac{1}{2}$ tons per sq. inch

had not resulted in the failure of the surfaces, though this enormous pressure had extruded the bronze bush, thereby increasing the working clearance. With this construction it would seem therefore that within the strength of the material it was impossible to overload a bearing.

With regard to lead bronze, Colonel Fell's experiments with this material had been somewhat disappointing, but in Mr. Lawrance's concluding remarks he thought Mr. Lawrance had explained the reason for this, namely, that in order to use a lead bronze the bearing housings must be designed in a special manner so as to ensure that the lead bronze was not overstressed. The method of facing steel shells with lead bronze was most interesting, and Colonel Fell intended to experiment with this at an early date.

The use of "Y" alloy pistons was referred to. This material had been found most satisfactory in England for pistons, but only in the forged condition machined all over. The lack of success with the cast pistons was more than probably due to lack of concentration on the problem by the foundry.

It was interesting to note the attention paid in America to inverted engines. In this country so far this type of engine had not gained much popularity owing to its supposed difficulties of installation.

Colonel Fell was very interested in the remarks on reduction gearing, as English designers who had visited America had brought back the view that this country was wasting its time producing geared engines when these had been proved to be quite unnecessary in America.

Salt-filled valves were referred to. Did the author think these valves were sound engineering practice, or merely a remedy for faulty cylinder design?

Colonel Fell would like further remarks as to how the D-12 supercharger increases the weight of the engine by only 5 lbs., as stated in the paper.

What was the power absorption of Roots' supercharger, and why was it necessary to place it to blow through the carburettor with all the difficulties which this system introduced?

The double magneto referred to was a most important development, and he hoped shortly would be adopted over here.

The revival of the Vee air-cooled engine was interesting. Colonel Fell felt sure that this type must come in again in spite of its greater weight than the radial air-cooled engine, in view of the high head resistance of the radial as compared with the Vee type engine.

With regard to type testing, Colonel Fell did not believe in the full power endurance test. In his opinion such a test represented an abnormal condition. No aircraft engine was ever called upon to run continuously at full throttle at ground level, and if the endurance test had to be carried out at full throttle it would result in the use of lower compression ratios than were desirable or necessary in view of the fact that one of the conditions was that the type test should be run on standard fuel. The full power test in the British type test is of one hour and is carried out at maximum permissible r.p.m., *i.e.*, 10 per cent. in excess of the normal r.p.m., the higher speed of course reducing the tendency to detonation at the full throttle running.

REPLY TO THE DISCUSSION.

With regard to the overhead camshaft on the air-cooled Liberty engine, and the question of expansion, of course the camshaft drive shafts are equipped with splines, so that expansion of the cylinders is taken care of there. If one cylinder is not firing, naturally there will be a certain disalignment because that cylinder will be less hot than the others, but you must remember that the cylinder barrel is steel and only the head is aluminium, and except for what difference of

temperature there may be between a water and an air-cooled cylinder, there is no difference in expansion of the barrel. There is a slight additional expansion of the head due to the additional heat in an air-cooled cylinder, but so far as I know, not to an extent which will cause any trouble. At any rate, I have never heard of it. With regard to the gear, I agree that if you could easily measure the thrust of the propellers on different power plants, it would be very much better to include the efficiency of the propeller in rating the engine, but it is very difficult to determine this except by elaborate tests; indeed, it seems almost impossible. As to the Roots' supercharger, I do not know whether I made myself quite clear about this. The supercharger is mounted in the same way as a turbo-driven supercharger, that is to say, with the carburettor located between the engine and the supercharger. The air delivered by the supercharger is bypassed into the open air until it is necessary to use it to supercharge. There is an altometer which is connected with the manifold, and the pilot, by regulating the bypass throttle, maintains ground level pressure all the time. With regard to the weight of 0.6 lbs. per h.p. taken for the weight of the radiator and water pipes for engines of moderate speed, as compared to high-speed engines, the amount of heat dissipated in the radiator is a function of horse-power, and more or less independent of the speed of the engine.

Mr. Thomas asked a question with regard to the comparative merits of air and water cooling in regard to the weight of the fuel. Undoubtedly the very lowest fuel consumption arrived at by the water-cooled engine generally is superior to that of the air-cooled engine at the present time, but the two types have different work to do. Where you have long-distance bombing and where the machine has to stay in the air for many hours, it is possible—although I do not believe it is necessarily so—that the water-cooled engine would be the best type. What we air-cooled people maintain, however, is that for short flights and for pursuit aeroplanes in military work, the air-cooled engine, owing to its overall weight, is very much lighter than the average water-cooled engine, and therefore has a great advantage which can only be perhaps overcome if the 'plane has to be in the air a very considerable number of hours. As to the standard American fuel, for the type tests we use what is known as aviation gasolene, which contains no benzol whatever. For convenience, some of the tests at McCook Field used fuel containing about 20 per cent. of benzol, but in the type tests we are not allowed to use any benzol at all. As a matter of fact, the fuels we are getting in America are getting worse instead of better. We are trying to get a higher m.e.p. all the time and are to a certain extent succeeding, but the fuels are getting worse and we may have to lower the compression for standard service conditions if the fuel gets much worse. Colonel Bristow mentioned a rubbing factor of 32,000. I am not at all surprised, if the big end is properly designed and there is a proper supply of oil freely supplied, even only at 60 lbs. pressure. It is quite reasonable and should be possible. With regard to the gear standing up to the engine or the engine standing up to the gear, it is quite true that if you take a very strong gear and put it on a weak engine it will break the engine, whilst if the gear is weaker than the engine the gear will break. In almost all our gear reduction systems we are using a type of spring coupling which eliminates a great deal of the wear on the gear and seems to make the whole operation more satisfactory. Although I do not doubt that with some of the newer and very accurate gear cutting at the present time we should be able to get along without the spring coupling, yet we have become so wedded to it that we shall probably continue to do so, because of the added safety.

With regard to the American type test, that test as at present defined consists of half an hour at full power, then 45 hours at nine-tenths full power, and finally 4½ hours at full power. This test is less severe than the test you are now running in this country of 100 hours, although I think it is slightly more

severe than your former 50-hour test. However, the present test in our opinion, and in the opinion of most aeroplane engine constructors, serves no useful purpose because it is not severe enough. As a matter of fact, we are not following the requirements mentioned above, but are applying a more severe test, although the Government have not altered their regulations. Our test consists of 50 hours at full power without any reduction whatever. We tear down at the end of 5 hours, 15 hours and 30 hours, under the supervision of an inspector, in order to discover whether anything has happened to the engine. If, for instance, a crack has started, we will discover it before the engine is wrecked. As you all know, it takes precious months to rebuild a wrecked engine, and by the method we have adopted we get information as to whether a crack is beginning instead of merely knowing that we have a wreck. We can also in this way discover what part failed first. There is a further point, that instead of continuing on with the standard test after a discovery of this sort, we can proceed on more severe lines and at higher revolutions, and in that way develop the engine as fast as possible. Thus we are able to get ahead more quickly and save time, and prevent the necessity for running all-night tests which get you into trouble with your neighbours in peace-time. As to the blast when testing air-cooled engines, with our standard type test we work with a four-bladed club which is designed to give somewhat more blast near the centre than an ordinary propeller. All our power curve tests, however, are run in a wind tunnel with an artificial blast from an electric motor. The reason for the location of the exhaust and intake ports in the Liberty air-cooled engine is as follows: the air comes into the Vee between the cylinders and passes out between them to the outside. It is found necessary to cool the exhaust port first, and it is for that reason the exhaust ports are in the centre. With regard to the clearances when Kelmit is used, as in the Wright Model E, which was the old Hispano, the clearance is only slightly more than the required clearance if babbited. Where we have got into great difficulties in the United States is in trying to use Kelmit in constructions which were not suited for it. Kelmit is a bearing metal which cannot be very highly stressed. It is not a structural material which can be used except in very thick sections. We have had such good results with it on the E-4, however, as a bearing material, that I do not doubt, if it were properly used, it would be all right on other engines as well. Generally speaking, I have nothing for or against it. I cannot give the information asked for as to the amount of oil passed through the engine per hour. Yes, we have had difficulties in the casting of "Y" alloy. The Aluminium Co. of America have been working for two or three years to find out how to cast it properly. I am not very familiar with foundry practice, however, and I am afraid I cannot tell you any more about it except that we now get very good castings; but it took a long time. Perhaps with the size of valve that Mr. Fedden is now using, salt cooling will not show a great advantage, but we certainly found great advantage when we took the valves that were being used on the Model E Wright Hispano and salt-cooled them. As a result we were able to run the valves for 100 or 150 hours without any trouble, whereas formerly that was not the case, and I think that the greatest proof of the advantage of salt cooling is the trouble that we used to have and the good results we are now getting. As to the reliability of magnetos, unfortunately we have the same troubles as you apparently have here. As to the starter system which has been mentioned, there is a little flywheel working through a clutch, similar to the old Mercedes clutch, with a spiral spring which grips the shaft and also a disc clutch which slips when the load becomes too great. This arrangement will pull over the stiffest engine. There is also a company making the Eclipse starter, which is somewhat lighter and smaller. There is a good deal of torque connected with this device, however, and it has to be taken care of in the starter mounting. I should say that the rear part of the crankcase of the Bristol engine would have to be strengthened to take care of the torque from such a starter.

The CHAIRMAN, proposing a vote of thanks, said: In proposing a vote of thanks to Mr. Lawrance, I should like to take the opportunity of saying what I believe is the feeling of all of us, that we have been filled with admiration during the last few years at the rapid and very striking development of aircraft engines in America, and that we are particularly grateful to Mr. Lawrance for what I can only call a masterly survey. He was good enough to refer to what he called the honour of lecturing before us, but I can assure him that if he leaves us a year in which to digest what he has given us this evening, and then comes over here again, he will very soon find that honour thrust on him once more.

The vote of thanks was carried with acclamation.

PROCEEDINGS

TENTH MEETING, SECOND HALF, SIXTY-FIRST SESSION.

The Tenth Meeting of the Sixty-First Session of the Royal Aeronautical Society was held in the Society's Library, at 7, Albemarle Street, London, W.1, on Thursday, January 21st, 1926, when a paper on "The Schneider Cup Race, 1925," was read by Major J. S. Buchanan, Associate Fellow.

Air Vice-Marshal Sir W. S. BRANCKER said: Major Buchanan is going to speak to us on the subject of the Schneider Cup. As you all know, he was the representative of the Air Ministry during the autumn in America.

THE SCHNEIDER CUP RACE, 1925

BY MAJOR J. S. BUCHANAN, ASSOCIATE FELLOW.

I am indebted to the Air Ministry for permission to give this paper, but at the same time I am directed to say that the views expressed herein do not in any way represent the official view of the Air Ministry, nor indicate the policy which is to be followed.

The Schneider Cup was presented by M. Jacques Schneider to the Aero Club of France for the purpose of International Inter-Club Races. The Deed of Gift provides that the race shall be open to seaplanes of all descriptions.

The first race was held by the Aero Club of France at Monaco in 1913 and was won by Provost flying a Duperdussin seaplane at a speed of 45.4 miles per hour.

The next race was held at Monaco in 1914 and was won by C. H. Pixton on a Sopwith seaplane at a speed of 86.4 miles per hour.

The contest was in abeyance during the period of the European War, and the next race was held at Bournemouth in 1919. The winner of this race was Janello flying a Savoia flying boat with a speed of 124.9 miles per hour. This race was subsequently declared null and void because of certain irregularities.

In the following year, 1920, the race was held at Venice and was won by Bologna flying a Savoia flying boat at a speed of 107.2 miles per hour.

In 1921 the race was again held at Venice and was won by Buganti in a Savoia flying boat at a speed of 114 miles per hour.

In the following year the race was at Naples, and Captain Biard in a Supermarine Sea Lion won with a speed of 146.1 miles per hour.

The race in 1923 was held at Cowes, and it may be said that this race inaugurated a new era in the Schneider Cup trophy. A highly-organised and well-equipped team entered from America and proved that the development of high-speed aircraft in that country had gone ahead of similar development in Europe. The race was won by Lieutenant Rittenhouse on a Curtiss Racer C.R.3 at a speed of 177.4 miles per hour.

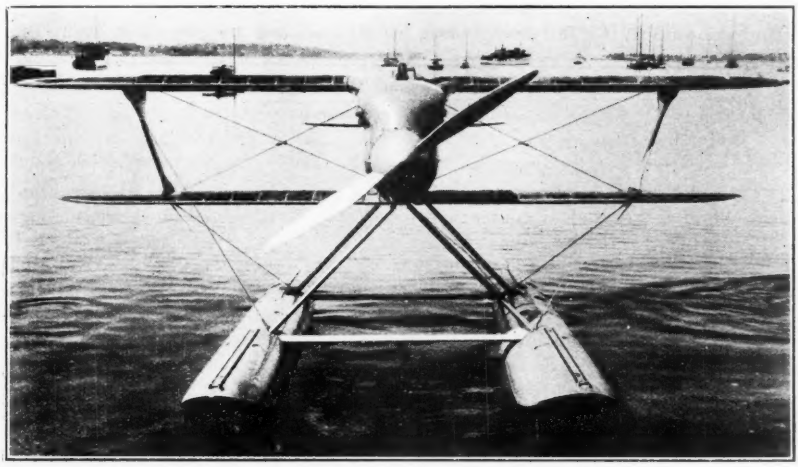
In the following year, 1924, the race should have been held at Baltimore in October, but owing to misfortune during preliminary trials, the European contestants did not appear and the American authorities declared the race off.

The last race was held at Baltimore on October 25th, 1925, and was won by Lieutenant Doolittle on a Curtiss Racer at a speed of 234 miles per hour.

This is the race which is of particular interest at the moment and to which I propose to devote a considerable proportion of this paper.

In Table I. is given a tabular summary of the results of these contests. The most striking feature is that the speed of the winning aircraft has increased from 45.4 miles per hour in 1913 to 234 miles per hour in 1925. In the space of twelve years the speed of the winner has increased five-fold. This increase is so remarkable that it seems superfluous to make any comment on the great progress that has been made in aircraft and engine design during this period.

The Schneider Cup Race may be viewed from two aspects. The first is the sporting and spectacular point of view, and the second is the technical and scientific. There is no doubt that racing will always improve the breed, whether it be merely animal racing or combined animal and mechanical.



Curtiss Schneider Cup Racer, R.3.C.2, 1925.

A glance at Table I. will show the speed improvement which has taken place annually and that part of it which may be credited to racing only. From 1913-1914 the speed nearly doubled. From 1921-1925 the speed has again doubled. In the period 1914-1919 the development of aircraft followed on the necessities of war, but in peace-time it would appear, if these figures can be taken as a fair criterion, that the spirit of rivalry and emulation arising out of racing can be relied on to keep up the rate of progress.

I suggest that it is essential for progress in aviation to maintain these contests, but whether it is right that such races should be confined to expensive instruments such as the Schneider Cup type, and at a cost which can only be borne by Governments, is a question which deserves the very careful consideration of the sporting authorities in all countries.

Failing Government support, the cost of this racing will naturally fall on private owners, and the expense is such under present conditions that no private owner can support the cost for any length of time. The America Cup illustrates this point.

The development of high-speed aircraft is now an essential part of the programme of experimental work of the Air Ministry, and it so happens that part of this work coincides with the existing rules for the Schneider Cup Race.

The original Deed of Gift of this Cup provided for inter-club racing, and I doubt if it was ever contemplated that the contest would in time become a competition between Governments.

I would suggest that aircraft racing authorities might follow the lead given by yachtsmen and introduce international races for small aeroplanes in the same manner and under somewhat similar conditions to that prevailing for the international races for the 6-metre class yachts.

So far as this country is concerned, it is only in very recent years that the Air Ministry have been able to help with the development of racing aircraft. In 1922 it was decided, in order to encourage high-speed racing aircraft design, that the Air Ministry would purchase the winner of any international trophy if of British design and manufacture. This was done in the case of the Bamel and Sea Lion. As a further step it was decided that aircraft which had been developed for research and experiment at high speed would be lent, subject to certain conditions, to the design firm if they wished to enter for international races.

The Gloster II. and Gloster III. and the S.4 come under this category.

In America, on the other hand, the aeroplanes are ordered by the Government Departments from the makers for the purpose of racing, and the actual racing is carried out by the two branches of the Air Services concerned.

After the failure of the Gloster II. seaplane in August, 1924, it was realised that we had a great deal to learn on the subject of high-speed seaplanes and that the experience to be gained by the development of aircraft of this type fully justified the allocation of a proportion of the money voted for experimental purposes to work of this nature.

The Gloster Aircraft Co. had devoted considerable study to problems of this nature and were asked to proceed with the redesign of the Gloster II. If this redesign proved satisfactory it was to be loaned to the Gloster Co. for the purpose of racing in the Schneider Cup in America in 1925.

In 1924 the Supermarine Aviation Co. had been engaged in developing for the Air Ministry a racing flying boat with an engine in the hull and a geared drive to the propellers. This design was not completed because of difficulties experienced with shaft driving and gearing, and early in 1925 it was decided to abandon the work already done and to proceed with a redesign using a Napier Lion engine.

The Supermarine S.4 was completed early in August, 1925, and carried out successful trial flights from Calshot during that month. During these trials a world's speed record for seaplanes of 226.7 miles per hour was set up, but this record was not destined to live very long.

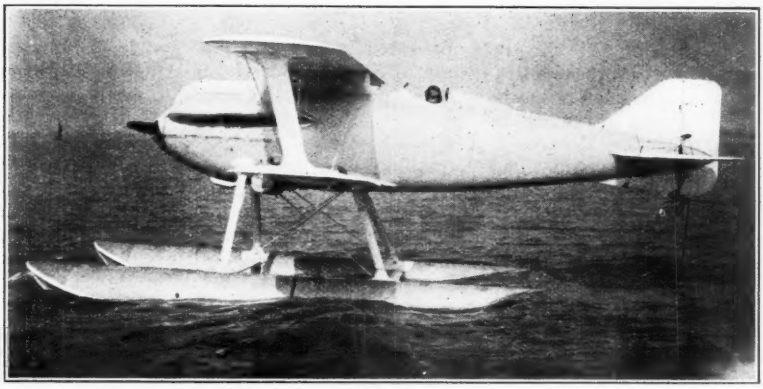
The Gloster III. seaplanes were completed about the same time and carried out preliminary tests at Felixstowe. Owing to bad weather conditions it was not possible to do much flying on these seaplanes and they were shipped to America before they had been fully tried out. The Royal Aero Club had set up a special Committee to deal with the organisation of this race, and this Committee decided to send out a fully-organised team with Captain C. B. Wilson in charge. The aircraft sent out consisted of the Bamel fitted with floats, which was to be used as a practice machine, the S.4 and two Gloster III. seaplanes. Only one Gloster III. was entered for the race, the other being held in reserve.

The team left London on the "Minnewaska" on September 26th, arriving at Baltimore on October 7th. The arrangements made to house the aircraft and mechanics in charge of them were unsatisfactory. The weather conditions were bad and the team had to overcome considerable difficulties in unpacking and assembling the racers at Bay Shore, Baltimore.

I should like to emphasise at this point that races of this nature require that ample facilities should be available for contestants, and to suggest that it is the duty of holders of the trophy to see that such facilities are available. I suggest that holders should not delegate responsibilities of this nature to any other body, nor should the F.A.I. recognise or permit such delegation. At the same time I should like to make it clear that the difficulties experienced did not affect the result of the race in any way, but it is conceivable that similar circumstances might arise either in this or in other races which would have this effect.

It was found impossible to erect the Bamel for practice work, and the weather conditions being poor, the pilots had little practice round the course. Neither was time available to test out the Gloster III. seaplane thoroughly.

On Friday, October 23rd, the navigability and watertightness tests were carried out. Whilst carrying out a preliminary flight prior to entering on the navigability tests proper, the S.4 stalled and crashed into the sea. The pilot, Captain Biard, escaped unhurt.



Gloster III., 1925.

The spare Gloster III. seaplane with Mr. Hinckler as pilot was got ready for the tests to replace the S.4, but was unable to complete the tests before dark on that day.

The succeeding two days were unsuitable for flying and the race was postponed until October 26th. At dawn on the morning of the 26th, Hinckler on the Gloster III. started out on the navigability test, but the sea had not moderated sufficiently from the storm of the previous day and the undercarriage failed on the first landing. The damage done was not extensive and the pilot was unhurt.

The race commenced at 2.30 p.m. on October 26th. The actual contestants in order of start were :—

(1) Lieutenant Doolittle, U.S. Army, Curtiss Racer.
(2) Captain H. Broad, Great Britain, Gloster III.
(3) Lieutenant Cuddihy, U.S. Navy, Curtiss Racer.
(4) Lieutenant Offstie, U.S. Navy, Curtiss Racer.
(5) H. G. de Briganti, Italy, Macchi Racer.

It was evident after the first lap that the Gloster III. was not nearly fast enough.

The arrangements for keeping the crowd informed of the lap times and speeds of each of the seaplanes were admirable. A good system of loud speakers was installed and it was possible to follow the position of the race from beginning to end. In addition, the speeds for a completed lap and the mean speeds over the laps covered were posted on the notice boards within a minute of the seaplane passing the turning point. These arrangements added very considerably to the interest of the race from a public point of view and might well be copied.

Table II. gives the speeds and times over each of the seven laps of the course. Each lap measured exactly 50 kilometres and the total distance 350 kilometres or 217.8 land-miles. Only three seaplanes finished the course.

Lieutenant Doolittle was an easy first, Captain H. Broad was second, and H. G. de Briganti third. This would not have been an unsatisfactory result for Great Britain if there had not been about 30 m.p.h. speed difference between each of the contestants who finished.

Lieutenant Cuddihy had a forced landing due to a lubrication failure, and Lieutenant Offstie a forced landing due to the failure of a magneto drive. In both cases the landings were successfully accomplished without injury to the pilot or aircraft.

The piloting of the race provided an interesting contrast. Lieutenant Doolittle flew a magnificent course, flying low down and making tight well-banked turns round the marks. M. Briganti flew the course in a similar manner, but this was not so remarkable, observing that his seaplane was nearly 60 m.p.h. slower than the Curtiss. The U.S. Navy pilots, Lieutenants Cuddihy and Offstie, flew a wide course, making wide sweeping turns. I am informed that this was done as a result of a series of tests carried out by the U.S. Navy Department which had indicated that it was possible to maintain a higher average speed by flying a wide course in this way. Before seeing the race I had thought that such a condition was possible, but I am convinced from observation of Lieutenant Doolittle's flying that tight-cornering is an advantage if the pilot and the aeroplane can stand the accelerations, and if the pilot has had sufficient practice and experience in this type of flying. In this connection it is worth noting that Lieutenant Doolittle has carried out some valuable experiments in accelerations in flight and no doubt he knew exactly how much acceleration he could stand for a given period. There can be no doubt that his knowledge of this subject was of great assistance to him during the race. When tested over the speed course the following day, the winner created a world's record speed of 246 m.p.h. His best lap time was 235 m.p.h., so that over a triangular course 50 kilometres long, he dropped only 11 m.p.h.

Captain Broad flew a course intermediate between the U.S. Army and the U.S. Navy. He was handicapped by having had little practice on the Gloster III., which was actually slightly tail heavy and slightly unstable directionally. The maximum horizontal speed of this aeroplane is not known with accuracy, but it is probably about 218 miles per hour.

In Table III. figures are given for the maximum horizontal speed of all the aircraft of which I have been able to obtain details. Some of these figures are estimates, but they are based on the most reliable information I have been able to get and should therefore be used as approximations only.

In concluding this part of the paper I should like to place on record my appreciation of the help that was spontaneously given with characteristic speed by our many friends in America. Although it was thought that arrangements might have been better, it is but fair to say that all concerned did their utmost to help us out of our many difficulties.

With regard to the more technical aspects of the race, I have tried to summarise in Table III. all the information I have been able to collect on the

TABLE I.

Year.	Place of Meeting.	Distance.	Pilot and Aircraft.	Average Speed.	Engine.
1913	Monaco ...	172.9 miles	Prevost, Deperdussin Seaplane ...	45.4 m.p.h.	160 h.p. Gnome.
1914	Monaco ...	172.9 ,,	Pixton, Sopwith Seaplane	86.4 ,,	100 h.p. Mono Gnome.
1919	Bournemouth ...	231 ,,	Janello, Savoia Flying Boat ...	124.9 ,,	Isotta-Fraschini.
1920	Venice	232.7 ,,	Bologna, Savoia Flying Boat ...	107.2 ,,	Ansaldo.
1921	Venice	230.4 ,,	De Buganti, Savoia Flying Boat ...	111.4 ,,	200 h.p. Macchi-Isotta.
1922	Naples	230.6 ,,	Biard, Supermarine Flying Boat ...	146.1 ,,	450 h.p. Napier "Lion."
1923	Cowes	214 ,,	Lt. Rittenhouse, Curtiss C.R.3 ...	177.4 ,,	400 h.p. Curtiss D.12.
1925	Baltimore ...	217.8 ,,	Lt. Doolittle, Curtiss R.3.C-2 ...	234.4 ,,	619 h.p. Curtiss V. 1400.

TABLE II.

SPEEDS ATTAINED AND FLYING TIME CONSUMED, BY LAPS, IN SCHNEIDER SEAPLANE RACE.

The speeds attained and the flying time consumed, by laps, in the Schneider Seaplane Race are shown in the following table. (The upper figures in each block show speed attained, the lower figures the flying time, in minutes and seconds, for the lap.)

Pilot.	1.	2.	3.	4.	5.	6.	7.	Total time.
Lieut. Doolittle ...	222.157	233.573	234.326	234.459	233.422	234.508	235.036	—
	8–21.20	7–58.85	7–57.31	7–57.04	7–59.16	7–56.94	7–55.87	56–6.37
Capt. H. Broad ...	194.275	198.637	201.536	201.412	199.776	199.644	199.086	—
	9–35.71	9–23.07	9–14.97	9–15.31	9–19.86	9–20.23	9–21.80	1–5–30.95
H. G. De Briganti	166.813	155.790	173.858	173.720	170.057	168.720	171.593	—
	11–10.49	11–57.93	10–43.32	10–43.83	10–57.70	11–2.91	10–51.87	1–17–28.05
Lieut. Cuddihy ...	211.590	221.128	222.217	223.081	222.571	222.584	—	—
	8–48.60	8–25.80	8–23.32	8–21.37	8–22.52	8–22.49	—	—
Lieut. Offstie ...	207.959	219.246	218.980	223.033	223.041	—	—	—
	8–57.83	8–30.14	8–30.76	8–21.48	8–21.40	—	—	—

TABLE III.

CHARACTERISTICS OF RACING SEAPLANES.

	Sea Lion.	Bamel.	Gloster II.	Gloster III.	S.4.	Curtiss 1923.	Curtiss 1924.	Curtiss 1925.
Total Weight (lbs.) ...	3230	2770	2500	2687	3191	2747	2640	2710
Wing Area (sq. ft.)...	285	200	150	152	136 (flaps)	148	162	144
Wing Loading (lbs./ sq. ft.)	11.3	13.8	16.6	17.7	23.5	18.5	16.3	18.8
H.P. Loading (lbs./ h.p.)	5.6	4.8	3.95	3.8	4.6	6.0	5.3	4.4
Area of Fuselage. Max. Cross Sect. (sq. ft.) ...	11.5	—	9.1	9.1	8.1	7	7	6.5
Prop. Diar.	8′ 8″	9′ 6″	9′ 10″	7′ 9″	8′ 0″	8′ 6″	—	Wing rad. 174 sq. ft.
Prop. Pitch	10′ 6″	12′ 10″	15′ 11″	8′ 11″	9′ 3″	9′ 4″	—	7 8″
Engine Wt. (lbs.) ...	920	920	840	730	730	690	690	10′ 0″
Engine h.p.	575	575	633	700	700	460	500	660
Engine r.p.m. ...	2300	2300	2500	2700	2700	2300	2300	619
Speed on Straight (m.p.h.)	155	189	210 estimate	218	237	194	227	2350
Landing Speed, (m.p.h.)	63.5	75	79	80	90	85	80	246
								85

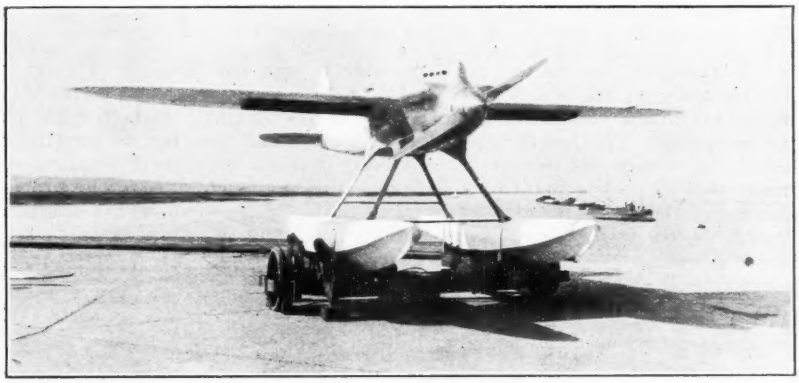
more important racing seaplanes of recent years. Unfortunately for the accuracy of this table the information has had to be gathered from a large number of sources and it has not been possible to check all the details with absolute accuracy. I believe, however, that they are sufficiently accurate as a basis of comparison.

In the first place I should like to draw attention to the Bamel seaplane. This machine existed as an aeroplane in 1923, and if a pair of floats had been fitted to it as has now been done, its speed would have been within 5 m.p.h. of the Curtiss winner, even with the disadvantage of the Lamblin radiator. It is fair, therefore, to say that except for wing radiators and Reed propellers in 1923 we were as far advanced in racing types as America.

It is from 1923 that we failed to keep abreast of our competitors.

Consider in what respects the Curtiss Racers in the last Schneider Cup Race were superior to the British entries, and some indication will be obtained of the direction in which we must advance. The principal points of superiority were :—

(*a*) General cleanness of design and absence of parasitic resistance (except possibly in the case of S.4).
(*b*) Wing radiators.
(*c*) More efficient propellers of the latest Reed type.
(*d*) Better trained pilots and a settled organisation for racing.



Supermarine S.4, 1925.

The only point on which British designers can fairly claim superiority is in float design. Both the Gloster III. and S.4 were cleaner on the water and had a much cleaner and a much quicker take-off than either the Curtiss or Macchi Racers.

(*a*) It would appear from analysis that body drag is the most important factor. If a good high-speed wing is chosen in which the ratio of maximum lift to minimum drag is of a high order, improvements in wing forms can only give increases of speed of a minor order. It is also apparent from analysis that an increase in landing speed without change of any other details will not produce any important gain in speed.

On the other hand, the body drag is the largest individual drag and much of it is probably due to apertures and projections. From an analysis made by Mr. Glauert and Mr. McKinnon Wood of the Curtiss Racers (aeroplanes) of 1923, it appears that the body drag of this aeroplane should be from $2\frac{1}{2}$-3 lbs. per sq. ft. of frontal area at 100ft. per sec. If this drag could be reduced to

1½lbs. per sq. ft., it is estimated that a gain of 8 per cent. speed would result. The resistance of a good streamline shape at 100ft. per sec. is about 1.2 lbs. to 1.3 lbs. per sq. ft., but it is unlikely that this figure can be achieved on an aeroplane because of the cockpit opening and minor obstructions. Model tests at the N.P.L. indicate that the cockpit opening with wind screen and pilot's head will increase this resistance to 1.7 lbs. per sq. foot. It is possible, therefore, that as much is to be gained by a carefully faired and streamlined body as by an actual reduction in the cross sectional area. Obviously it would be better to reduce the drag by both methods, but the reduction in cross sectional area of the body is limited by the size of the pilot and the space necessary for instruments and flying of the aeroplane.

In the case of the Schneider Cup racers, the drag of the floats is an important factor. The resistance of these should be nearly as low as that of a good streamline shape, *i.e.*, 1.3 lbs. per sq. ft., so that a diminution of frontal area alone offers possibility of improvement. A reduction in aircraft weight would naturally tend to reduce area.

(*b*) The Curtiss Co. claim that the introduction of wing radiators in place of radiators of the honeycomb type improved the speed of their aeroplanes by 20 m.p.h. at speeds in the neighbourhood of 250 m.p.h. The Lamblin radiator is intermediate in head resistance between the honeycomb and the wing type, and it is probable that the fitting of wing radiators will increase the speed of our existing aircraft by about 8-10 m.p.h. It is therefore essential that future racing aeroplanes be fitted with surface radiators.

(*c*) Owing to the limited time available it was not possible to carry out propeller tests on the S.4 or Gloster III. before they went to America. Had time been available there is little doubt that the performance of both could have been improved. The forged type of light alloy Reed propeller as used by the Curtiss Co. is reported to give better results than the bent sheet type and it is claimed that an improvement of 3 per cent. efficiency is obtained. The propeller efficiency of the seaplanes of 1925 is about 80 to 85 per cent. at full speed and probably as low as 8 per cent. at hump speeds.

(*d*) In my opinion it is of the first importance to have highly-trained pilots for these races. In America, high-speed racing is a matter of Service training rather than of sport. All the American pilots who flew in the Schneider Cup Race were experienced in racing and all of them were fully trained.

Apart from a few flights before leaving this country, none of our pilots had any experience of flying or cornering at 200 m.p.h. It would be ridiculous to spend a great deal of time, money and energy in the design and construction of high-speed aircraft without taking great pains to train the pilots on whom the final responsibility rests.

Not much can be gained by reduced engine weight nor by reduced structure weight, except for the reduced resistances of floats and exposed structural members. The engines are approaching 1 lb. per h.p., and even if it were possible to reduce this to ½lb. per h.p., the gain in speed would not be more than, say, 2 per cent.

The structure weight is bound up with the question of safety and strength.

American racers are in general built with higher load factors than ours. The Curtiss Racer for 1925 was sand-loaded to a factor of 10 on the front spar and other components were in proportion. Neither the Gloster III. nor the S.4 were up to this standard. It is quite certain that the strength of the undercarriages fitted to our seaplanes should be increased to meet the landing and taking-off conditions. The load factors on the aero structure will be determined by the accelerations obtained in cornering.

High-speed diving need not be indulged in for the Schneider Cup Race, and in this respect it differs from the Politzer trophy.

It is probable that Lieutenant Doolittle did not exceed an acceleration of 4 G. during the race, and on this basis a calculated load factor of eight appears to be adequate.

The true load factor will be a little higher than this in view of the redundancies in the structure and the natural conservatism of the assumptions made in calculating the loads in the members.

Under these circumstances I see very little hope of any reduction in structural weight and no gain in speed is likely to accrue from this source.

As I see it, if we are to increase our speed in the next race, it is essential to attack the following main points :—

(1) The body drag must be reduced both by reducing size and increasing efficiency.
(2) Wing surface radiators must be used.
(3) The best type of propeller must be fitted, and to ensure success in this direction the aircraft must be carefully tested out before entering for the race.
(4) Highly-trained pilots must be available to fly the aeroplanes.

It will not be possible for Great Britain to race for the Schneider Cup Race in 1926, nor will there be any other entrants. The Royal Aero Club have asked the National Aeronautic Association of America to postpone the next race until 1927, and if this is agreed to, I believe we shall more than hold our own.

Discussion

Mr. H. P. Folland said: Having played a small part in the 1925 Schneider Cup Race, I have found Major Buchanan's paper an extremely interesting one.

In reviewing the results of the race, one must consider the progress of racing machines from both sides. America has studied racing machines and has been building them since 1919, adequately supported by her Government, whose whole object was to develop the high-speed racing machine and to take world's records. The programme was carefully studied and, for the first time in aviation, engines were designed for the machine, which made it possible to produce bodies with the minimum cross sectional area. The propeller and radiator experts also collaborated with a view to making the most efficient radiator and propeller.

The results of adequate financial support and experimental work were seen in the 1923, '24 and '25 American races.

In England little has been done to design real racing machines; most of the work done was carried out by my firm—the Gloucestershire Aircraft Co.—until 1924, when the real first attempt was made to produce a racing seaplane with Government support. These machines had to be designed round a special boosted Lion engine, no engine specially designed for a small body being available. Until 1924 the only speed machine we possessed was the "Bamel," which had been in use in modified forms since 1921. This machine was built up from a Nighthawk (scout) fuselage and cannot be considered a real attempt as a racing machine. This machine at one time made 212.2 m.p.h. average speed over the one kilo course.

Major Buchanan mentioned the principal points of superiority of the winning Curtiss plane.

Regarding cleanness of design the engine designers can also help in this

direction by studying the cross sectional area of the engine; the Gloster III. body area was 7.4 sq. ft. plus 1.7 sq. ft. for fairings over cylinder blocks and pipes, etc., making a total of 9.1 sq. ft.

With reference to wing radiators, these undoubtedly improve the cleanness and improve top speed considerably. Although we saw wing radiators on the Curtiss Racer the end of 1923, we had yet to solve the manufacturing difficulties which were numerous. I am pleased to say we are now able to make them.

I agree with Major Buchanan that more efficient propellers are required and a great deal of experimental work can be done in this direction.

With regard to the propellers used on Gloster III., there appeared to be indications of loss in efficiency which may be due to one or more of three possible causes :—

Excessive tip speed.
Torsion of tip due to extreme C.P. movement.
Straightening out of twisted blade under centrifugal tension.

From Table III. we get r.p.m. also propeller diameter of the 1925 seaplanes. It is interesting to note that the propeller tip speeds for Gloster III. work out at 1,120 feet per sec. and for the Curtiss plane 950 feet per sec. approx.

Regarding pilots and organisation, I consider this one of the most important factors. There is little doubt that the American pilots had a great advantage, having had facilities to train over a long period on machines similar to the type flown in the race. Many hours had been put in by all their pilots and plenty of practice on cornering had been done. They were also well acquainted with the course.

Under the present arrangements it is almost impossible to train our pilots; firstly, we have few good civilian pilots to choose from, and secondly, the good pilots are mostly engaged on other important test work which prevents their devoting sufficient time for practice. It is of little use designers studying the cutting down of resistance, etc., if the pilot loses 5 to 10 m.p.h. through lack of training.

I also consider that the existing load factors on wings for this type of machine should be increased between eight and nine. It is already possible to get up to 4 G. on turns. This may be increased in future events.

I should like to thank Major Buchanan for his excellent paper.

Mr. R. J. MITCHELL, after thanking the Lecturer for his valuable paper, said: I was fortunate enough to be present at the race in America last year and consider that the Lecturer has given us a very accurate and instructive account, and in addition a valuable historical sketch of previous Schneider Cup races.

I was particularly interested in the Lecturer's suggested methods of improvement for the British machines, and had hoped that he would enlarge upon this subject. I thoroughly agree on the importance he attaches to the body resistance, but consider that an item at least as important is the interference effect between wings and body. If we obtain a body with low resistance and are not very careful how the wings are attached, the resistance can very easily be doubled by the added effect of interference. The same thing applies to the methods of attachment of chassis members, tail plane, fin, etc., but to a rather less extent.

I wish to criticise the Lecturer's statement that a reduction in weight of engine from one pound per h.p. to half a pound per h.p. would only give an increase in speed of 2 per cent. I consider this statement is dangerous in view of the fact that we have engine designers here to-night, and it is likely to give them a wrong impression regarding the weights of their engines. I think that 2 per cent. is a very low estimate and would rather place it at $3\frac{1}{2}$ per cent. One must remember that a reduction in engine weight brings a further reduction

in structure weight of about 40 per cent. of the amount. This means that the wing area, tail area and cubic capacity of floats can all be reduced in proportion, resulting in a reduction of resistance of all these components. The resulting gain in speed enables a further reduction in weight to be made due to a reduction in quantity of fuel required. The accumulated effect of these reductions is very important.

Quite a lot of discussion has taken place regarding the suitability of the Napier "Lion" engine for racing purposes on the grounds that our fuselages were much larger than the American fuselages. Speaking entirely on the design of the S.4, it is only fair to state that a certain proportion of the 8 sq. ft. of cross sectional area was brought about by the cantilevering of the chassis from the fuselage, and but for this feature the fuselage cross sectional area could have been cut down considerably. At one time I thought that the "Lion" engine was at a disadvantage with the American engines, but I have changed my views rather, and certainly consider the "Lion" engine is capable of winning the Schneider Cup.

We learned a number of lessons from last year's race, and gained much knowledge and experience. I think if another effort is ever made, and we take full advantage of this, we have every reason to view the result with optimism.

Mr. G. S. WILKINSON said: During the reading of the paper I felt very comforted indeed on the subject of engine weight. I had feared the Lecturer might want engine weight reduced to $\frac{1}{4}$lb. per h.p.

I do not propose to enter into a discussion as to whether the "Lion" engine is better or worse than other types for installation in high-speed machines. The answer to this question can only be obtained from the results of trials of otherwise similar machines fitted with alternative types of engines.

Captain BIARD said: I have listened to the Lecturer with great interest, especially his remarks on the training of pilots for the Schneider Cup. I am afraid that this year, owing to lack of time, this training practically did not exist. Most of the pilots were lucky if they had $1\frac{1}{2}$ hours at full speed, and I am afraid that even if our machines had been as fast as the American's we should have lost the race from that cause. I also note that Major Buchanan says, "High-speed diving is not necessary in the Schneider Race"—I will take this to heart, but wish he had mentioned it before we went to America.

Squadron Leader HAIG said: From the little experience of racing which I have had it would appear extraordinarily difficult to tell how well one's cornering has been carried out. While flying in the Aerial Derby in 1922 I thought that my last lap was the best, but actually it was the worst. It would appear to be important for training purposes to provide two similar machines and for the pilots to compete against each other and to change over machines.

Commander J. C. HUNSAKER, U.S.N., said: I was very much interested to hear Major Buchanan's well considered paper on this subject. I think the object of having races at all is principally to delight and entertain the people, but the inquest is very interesting for the technical man. We ought to learn a lot from this race, though what we have learned is rather debatable. I would put the emphasis in a slightly different way. It is extremely desirable to improve the form of the machine's body and to reduce its area, which is principally a matter for the engine designer. You cannot divorce the design of the machine from the design of the engine. They must be taken together. It would be very enlightening if the Author would add to the tables he has given us one showing the comparative improvement of engine design with speeds obtained. What is wanted is not to reduce the engine weight per horse-power, but rather to double the power of the same engine keeping the same frontal area and the same weight.

This produces the most immediate gain in speed and that is what we have tried to do.

With regard to the arrangements for last year's race, as a stranger in a foreign country I feel I ought to apologise. I know one morning when I went round to see how things were I found them pretty bad. This was because the public were considered first, and it happened to be the worst place for the competitors. For the Schneider Cup race you have first to find a suitable stretch of water, then consider whether there will be space for a million people to see it. We had to improvise facilities for the competitors and the improvised facilities were unsuitable for the bad weather that came. Next year the public will have to have less consideration and the competitors more. In the case of the Cowes Meeting we had the water, and the American competitors were fortunate in obtaining facilities at Saunders Works in permanent buildings.

With regard to the conditions of the race itself, I think it is unquestionable that speeds will go up as engine and aerodynamical improvements are effected, but I doubt whether the constructional insides of the pilot will be improved. If certain excellent pilots can stand 4 G., others, equally excellent, cannot; they become dizzy. It seems to me unwise for the Schneider Cup race to develop into a test of pilots and not of seaplanes, and the suggestion occurs to me that the three-cornered course ought to be a five or six-sided one. There is no doubt in my mind that load factors of 10 or 12 ought to be required.

Flight Lieut. G. H. REID: This paper is very instructive in showing by the various performances of the different pilots how the winner of the race kept to the least variation in the time of the different laps.

If the time schedule of the laps be examined it will be seen that the English machine appeared to take off the water quicker than the others. In the air the American machines were much better on performance. If a curve of performance be plotted the flatness of the curve of the winner is outstanding. This indicates careful training, and aptitude for quick turning on these fast machines, which must have been carefully practised.

It would seem necessary to make special tests to pick out pilots who will be able to stand medically the effects of sharp corners at fast speeds and afterwards undergo special training.

The timing of the speeds of the machines during training must be carefully done, as it is very simple to make errors in timing of 1/10th second, and these errors on such fast speeds are quite appreciable.

Flight Lieut. BULMAN said: In such distinguished company I hesitate to give my views, suffering as I do from the disadvantage of not having witnessed the race.

It has been interesting to hear Commander Hunsaker's opinion that the increases in speed in recent Schneider Cup races have been almost entirely due to the development of the racing aero engine.

I am however better qualified to deal with the pilot's part of the game. In the limited time at their disposal I consider that the British pilots did very well. Speaking not as a racing but as a test pilot (and our pilots in the race had to be both) I know that the first hour or two in the air on a new aeroplane must be devoted to looking for weak points in control or installation. Further time is then required both for developing racing technique and for obtaining confidence in the actual type of machine which is to be used in the race.

With regard to the actual cornering, I feel sure that it must be the best policy to keep low round the corners. Lieut. Doolittle's extraordinarily high average speed appears to confirm this view.

It must be remembered that the pilot cannot look straight downwards at the turning point, but must always look down at an angle. Unless he keeps low a large radius of turn is necessary in order to keep the mark point in view during the turn.

When cornering in this manner, whilst it is important that both pilot and aeroplane are strong enough to stand the acceleration, it is imperative that the lateral and directional control be of a very high order.

Mr. HANDLEY PAGE said: I think if Major Buchanan could add to his paper details of the analysis to which he refers in his paper, it would make his paper more complete. I refer to the analysis made by Mr. Glauert of the different resistances of the aircraft taking part in the Schneider Cup. It would be very interesting to have this analysis printed with Major Buchanan's paper in the Journal.

The paper has brought out the necessity for the closest co-operation between the designer and the pilot if success is to be attained. It is rather alarming, therefore, in this country, when we are thinking of racing in a year's time, to read in the papers that the Air Ministry experimental vote is going to be cut in half. I don't know what we can do but hope. Perhaps by doubling our hopes we may be able to offset the halving of the vote. Although Faith, Hope and Charity are very good in other circles, in aviation we want to build on a more solid basis. I note that the Author sets forth in this paper that success is dependent on the successful co-operation between pilot and designer. I hope that that lesson will have its effect in the proper quarter and instead of the experimental vote being halved that it will be doubled, so that we can make the improvements which we see are possible from this paper.

Colonel W. A. BRISTOW said: I should like to raise one point and that is the effect on the design of British racing machines by reason of our policy of always holding handicap races. The Racing Committee of the Royal Aero Club have, on several occasions during the past few years, pointed out that as a result of always holding handicap races, very little progress was being made in this country in the design of racing machines and that in France and America where scratch races were the chief events the rate of progress in pure speed had been much greater.

Last year the club attempted to organise an International High-Speed Scratch Race, but there was no support from British manufacturers and the scheme fell through. This is unfortunate as more value would be obtained from such a race with two or three entries than from a handicap race with ten times that number.

The question of piloting was a difficult one and the desire to obtain a wider field for selection should not be construed as in any way reflecting upon the pilots who had flown for us in the past. It had to be remembered that the physical qualifications for this class of work were of a very special order, and it was hardly likely that we could expect to get a small band of super-trained high-speed specialists from the few pilots that could be spared from the already very small number of first class civilian pilots. Some people seemed to think that any first class pilot with sufficient nerve could do the job, but this is not so any more than it would be in any other branch of sport.

If all the drivers found at Brooklands any Saturday afternoon were transported in a body to drive in the Sicilian Road Race and they really tried to win, a very large percentage would probably be killed.

It has been suggested that the general conditions and the course for the Schneider Cup should be made easier and that the turns should not be made so frequent as every ten miles.

If all the difficulties are eliminated then there will be no need to run the race at all, competitors will send models of their machines to an international wind tunnel, which could be set up at Locarno, and a year or two later the winner will receive a certificate signed by all the Prime Ministers of Europe.

It is so often overlooked how very near we were to winning the race last year. During the contest 66⅔ per cent. of the American engines broke down, whereas the solitary "Lion" engine, designed for 450 h.p., gave 700 b.h.p. without any trouble whatever during the whole of the race.

It seems probable that had the race been a little longer the result might have been different.

Air Vice-Marshal Sir W. S. BRANCKER: There are some people who pooh-pooh racing and say that it has no practical value. Personally, I am a keen supporter of it. Now that we are at peace and bullets in the air no longer force us to excel in performance, design might have well stood still without racing, and to-day we might very likely have been flying at 180 miles an hour and patting ourselves on the back at such a performance. As it is, the Schneider Cup and other similar races have forced improvements on us. This race has also had the excellent effect of bringing our American friends to this country and taking us over to theirs.

I think the nation as a whole owes a debt of gratitude to the three firms who have borne the brunt of the Schneider Cup competitions—Supermarine, Gloucester and Napier—in this race which depends on organisation, and organisation is a matter of money. Last year our organisation was weak, partly because we had not enough time and partly because we had no money. The Royal Aero Club could not afford to organise the expedition on proper lines. There are two alternatives in the future; first, if we could only find a wealthy patriot to finance the operational side of the expedition—the salaries of pilots and mechanics during their training and at the race—all would be well. The other alternative is for the Air Force to take on the job and form a special unit for the purpose and train it for six months.

The question of publicity in air racing is always a difficult one and the Royal Aero Club is always having to meet troubles of this sort. I have come to the conclusion that you can only consider the public in handicap races and that in these big scratch competitions we must forget the public and concentrate on the efficiency of the race. I can promise nothing, but I think that, if our friends the Americans will put off the race until next year, the Air Ministry will see them through. Like the lecture itself, this is only personal opinion and not an official statement.

I know you will join me in thanking Major Buchanan very heartily for his most useful paper and the interesting discussion which followed.

Major BUCHANAN, in his reply to the discussion, said: I do not think I have many points to reply to. Mr. Mitchell disagreed with my figures about the estimated gain effected by lighter engines. I can only say he knows much more about it than I do, because he has done so much more work than I have on it. I obtained those figures from the very best estimates I have available and I do not think they are far wrong.

In reply to Squadron Leader Haig, as far as I can ascertain the fuel used by the U.S. Navy was 50 per cent. benzol and 50 per cent. petrol. What the U.S. Army uses, I am told even the U.S. Navy does not know. Pilots were equipped with parachutes and their instructions, I understand, were in case of accident to zoom up and pull out in the parachute. However, they did not use them, and all of them made perfectly good landings.

I quite agree with Commander Hunsaker that engine and machine design cannot be separated. We must improve on our existing engines. There is no

doubt that the Curtiss engine has been much improved. The frontal area has been very slightly reduced, but the power has been increased. The load factor required in racing aircraft will be determined by the accelerations which a man can stand. Doolittle's experiments showed that a man can stand 4 G. for a lengthy period and even 8 G. if for a very short period.

With regard to Dr. Reid, I think Broad in flying had a little trouble with his throttle which slipped back, but he did not notice it for part of a lap. He was also troubled with the stability of his machine and he lost a little speed on straightening out again after each turn. The extraordinary thing is that the one acceleration that the pilots complained of was the acceleration in taking off the water, simply because it was unexpected. At Felixstowe we did not get above some 3 G., but the amount of flying done was very small indeed. With regard to cornering, I am sorry Broad is not here, but as I understand it the control of the aeroplane is the biggest factor in cornering. I had noticed in the tables that the Gloster III. had relatively a higher mean speed than the Curtiss Racer for the first lap. I put this down to a better take off and acceleration on the first leg of the first lap.

With regard to Mr. Bramson's question, Doolittle gained a little height on every turn, but very little and it was probably accidental. The best method of attaching wings to the fuselage and the effect of the reaction of the slipstream on the wings are not known with any accuracy.

Flight Lieut. Bulman mentioned directional control. The directional control of the American racers is certainly better than ours. The directional control of the Gloster might have been improved, but there was not time to improve it. The directional control of the S.4 was good, but we did not see the aircraft cornering in the race.

The paper asked for by Mr. Handley Page was submitted to the Aeronautical Research Committee and I do not anticipate that there will be any objection to its publication in the Journal.

I am quite sure that Mr. Handley Page does not expect me to go into the question of the vote for experimental purposes.

I am indebted to Mr. Reed for his letter of the 5th February and I agree with his notes on the effect of the inner part of the blade on propeller efficiency. On the other hand, the " R " type of propeller gives a much stiffer blade less liable to distortion in the air, and it is because of this that a relatively higher efficiency should be anticipated. If the efficiency were so very nearly the same there would be little object in proceeding with the " R " type with its relatively higher cost of manufacture.

I cannot agree that the propellers used on the British seaplanes were the best possible. There are substantial reasons for the other view. This is not surprising considering the haste with which the aircraft were prepared and the very limited opportunity for full-scale testing. I am not in any way suggesting that either Messrs. the Fairey Aviation Co. or Mr. Reed failed to do their utmost, but all experience shows that with a new aeroplane careful propeller tests are essential to get the best results whatever type of propeller is used. I am still further from suggesting that " R " type of propellers might have been fitted. This was clearly impossible.

With regard to the remarks communicated by Mr. Simmonds, the figure of 1.2lbs. per square foot of frontal area for a streamline shape was taken from N.P.L. tests of forms suitable for aircraft bodies. Recent tests indicate that the figures given for body resistance can be improved considerably.

Scale effect does introduce an unknown factor into estimates based on wind tunnel tests at low V.L. values and a high pressure wind tunnel will certainly help to remove much of this uncertainty.

Mr. O. E. Simmonds (*communicated*): I think the value to this country of last year's Schneider Cup Race lies chiefly in the emphasis it has placed upon the interdependence of engine and machine design. Not long ago if any aircraft designer had dared to suggest a modification of a "type engine" for some special purpose, he would very soon have been informed of his proper sphere of action. Last year, so far as time permitted, everything was done to render the "Lion" engines most suitable for the machines, but in the future collaboration must be even more fundamental. Commander Hunsaker has stated that what we need to do "is not to reduce the weight per horse-power, but to double the power of the same engine, keeping the same frontal area and the same fuselage." I assume that here Commander Hunsaker means that higher speeds can be more easily obtained by increasing the horse-power and retaining weight per h.p. and frontal area constant than by endeavouring to decrease either the engine weight per h.p. or its frontal area. This is undoubtedly true, but it seems to me that what the engine designer requires to know is this—assuming that he can double the power of a certain engine for approximately the same weight per h.p. and frontal area, what is the relative importance of these last two factors? He may find that whilst doubling the power it is easy to keep them constant, in this case which factor should he aim chiefly at reducing? Or if, on the other hand, the proposition is impossible, on which factor can we most readily tolerate an increase? These are the fundamental considerations.

A generalised solution is barely possible; each machine must be treated on its merits. I have investigated the point so far as the S.4 is concerned and I think the results are not without interest. A seaplane on the lines of the S.4 with the same landing speed, having an engine of double the power (1,400 h.p.), but with the same weight per h.p. and frontal area as the direct drive Napier "Lion," would have a top speed of 257 m.p.h., *i.e.*, an increase of 20 m.p.h. over the S.4 itself. If to attain this power the weight per h.p. had to be increased 10 per cent., 3 m.p.h. would be lost; but if the frontal area of the fusefage were increased 10 per cent., the loss in speed would be only about half as much. So we find that for small percentages the effect on speed of a change in weight per h.p. is twice as great as that of an alteration in frontal area. In view of the tendency there has been to overestimate the effect of body drag compared with weight, this result is not only of some interest in itself, but it emphasises the necessity of considering carefully for each particular case the relative importance of power, weight and frontal area.

Major Buchanan gives for the drag of a good streamline shape at 100 ft. per second the figure of 1.2 lbs. per sq. ft. of frontal area. Possibly this result was obtained at a very low value of Vd, but in any case much better shapes have been tested. To quote only one, in Bairstow's "Applied Aerodynamics," p. 203, the streamline form of fineness ratio 6 at the highest Vd obtained, has a drag of only .825 lbs. per sq. ft. Nor do I think that the figure of 1.7 lbs. per sq. ft. is low enough for the racing bodies we are now using.

Actually, however, this whole question of drag in racing machines has become exceedingly complicated on account of the scale effect. And here I should like to draw attention to the very great advantage which the U.S.A. possess in their high pressure wind tunnel. I am uncertain whether the Curtiss designers benefited from its use in the 1925 machines, but for the future they have available an instrument of incalculable value for the prediction of full-scale results both on bodies, wings and complete aircraft.

I will give one example. For the design of racing aircraft the figure of pre-eminent importance in comparing aerofoils is the ratio (max. kL/min. kD). The full-scale Reynolds' number of the S.4 is approximately 11×10^6; the highest Reynolds' number we can obtain in a wind channel in this country is approximately 0.63×10^6. Bearing these figures in mind, let us turn to Report No. 217

of the National Advisory Committee for Aeronautics (U.S.A.), and note the effect of a variation of Reynolds' number on max. kL, min. kD and the ratio (max. kL/min. kD) of a symmetrical aerofoil section, N.A.C.A. 99, of 14 per cent. thickness :—

Reynolds' Number $\times 10^{-6}$.	Min. kD.	Max. kL.	Max. kL / Min. kD
.175	.0087	.361	41.5
.352	.0059	.376	63.7
.719	.0066	.408	61.8
1.070	.0062	.502	80.9
1.440	.0065	.508	78.2
2.950	.0053	.530	100.0

These figures speak for themselves, but when it is further borne in mind that there is very great variation in the scale effect as between various aerofoils, it becomes manifest that for high speed design the only value of a wind channel test at a low Reynolds' figure has been to give the designer the peace of mind induced by the assumption of a wise choice.

It is easy to gain 5 m.p.h. or to lose it in choice of aerofoil, and it is to be hoped that at an early date we may have the better guidance that a high Reynolds' number bestows. Possibly Major Buchanan will be able to say that a British high pressure channel will be an accomplishment of the very early future; until then our only hope of more reliable data lies in costly comparative full-scale tests.

I have been most interested in the views Major Buchanan has expressed and would like to add my thanks to those of other members.

Mr. S. A. Reed (*communicated*): I have seen Major Buchanan's lecture of January 21st, 1926, on the Schneider Cup Races of 1925, delivered before the Royal Aeronautical Society, and I wish to point out an error in his reference to the Reed Propeller. In accounting for the superiority of the American planes in that race, he ascribes it partly (*c*) to " More efficient propellers of the latest Reed type," also farther on he says " it is claimed that (for this later type) an improvement of 3 per cent. efficiency is obtained."

I examined the propellers of the Curtiss, Gloster and Supermarine planes at Baltimore, and I have also examined the drawings of all these propellers. I find that outside the spinner there is no appreciable aerodynamic superiority in the Curtiss propeller which could be assigned to the difference in type. The older type, which I call type D, carries its correct pitch angles from the tip up to about 15 inches radius, while the new type, which I call type R, carries the correct pitch angles up to about six inches radius. In type D, although the sections between 15 inches and 12 inches radius have no angle of attack, they are at least practically at neutral angles.

The Curtiss spinner cut the blade axis at $14\frac{1}{2}$ inches radius and the British spinners at a considerably larger radius, and in both cases the pitch angles at those points gave positive lift for the particular engine speed and flight speed in each case.

Every aerodynamical engineer knows by calculation that even in the best propellers the blade segments at about quarter blade length contribute barely 1 per cent. to the total thrust, and absorb less than 1 per cent. of the power, and that even a slightly negative angle of attack at this point has an effect which is immaterial. In spite of their knowledge to the contrary, I find that most engineers have a mental impression of the relative importance of this portion of the blade which is exaggerated and which they have difficulty in getting rid of.

Major Buchanan's estimate of 3 per cent. advantage in efficiency with the R type of Reed propeller is an error; I doubt if it amounts even to half of 1 per

cent. without the spinner, and with the spinner used by the British planes the advantage was negligible.

Even if the British racers could have obtained the R type of propeller, and there had been at 14in. radius a slight advantage in efficiency, they would not have been able to avail themselves of it because their larger frontal area required a wider spinner.

The British propellers, made by the Fairey Aviation Co., I found to be of high quality and my estimate of their efficiency in the Schneider Cup Races is that it was as high as is possible to obtain at the high revolutions of the engines used.

It has already been explained that it was only with the greatest difficulty that the Curtiss Co. succeeded in getting an R type propeller ready in time for the races of 1925. Previous to that propeller, the only one of the type was my own experimental propeller which was finished only a few days earlier and which had its first flight September 8th, 1925. Even at the present date there are only three of that type which have gone into service, namely, my own prototype above mentioned and the two Curtiss racers used in the Schneider Cup Races. The development of this type is closely tied up with special production methods which are now being worked out.

RESUMÉ OF TECHNICAL INFORMATION

Compiled by the Directorate of Technical Development (R.T.P.), Adastral House, Kingsway, London, W.C.2.

AIRCRAFT

France

Tests of the Albert Light Aeroplane

Les Ailes. 11.3.26. (1526.)

This light aeroplane is said to have carried out a new series of tests with remarkable results. It is fitted with a 40 h.p. radial nine-cylindered Salmson engine. At the tests the following results were obtained with full load :—

Climb to 3,280ft., 5min. 30sec.
,, ,, 6,562ft., 12 ,, 30 ,,
,, ,, 9,840ft., 21 ,, 30 ,,
,, ,, 13,124ft., 34 ,, 30 ,,
,, ,, 13,940ft., 39 ,, 20 ,,

The aeroplane with fire extinguisher, parachute, etc., weighs, in flying order, 8,532 lbs. The weight empty is 562 lbs., and the useful load, including the fuel, 291 lbs.

The estimated maximum speed is 90 m.p.h.

Italy

The Ansaldo 120 All-Metal Aircraft

L'Aviazione. 21.3.26. (2526.)

This aircraft is a parasol monoplane built entirely of metal, chiefly duralumin. The wings are fabric covered, the fabric being easily and quickly removed if necessary.

The fuselage is of duralumin tubing, with comfortable cockpits for pilot and observer. Dual control is fitted, and the pilot's view is said to be excellent. The tail plane is adjustable by the pilot.

The undercarriage is of the usual Ansaldo type with an additional strut to enable the aircraft to land safely on unsuitable ground. The wheels are fitted with Palmer tyres.

The radiator is of the honeycomb type.

The engine bed is specially simple to enable various types of engine developing 400 to 550 h.p. to be fitted. A 12-cylinder Vee, a broad arrow, or a radial engine can equally well be mounted. The flight tests of the aircraft were carried out with a Fiat A.20 engine, and a 400 h.p. Lorraine engine has also been tried.

Russia

Russian Transport Monoplane. Type K.1

L'Air. 1.2.26. (3526.)

A new transport monoplane, which can be fitted with a 170 h.p. Salmson engine or with a 185 h.p. B.M.W. engine, has been turned out by the Kiev workshops.

The wing is elliptical in plan and rests directly on the fuselage.

The chief characteristics are as follows :—

Span, 55ft.
Length, 35ft. 2in.
Wing area, 431 sq. ft.
Wing loading, 10.09 lb./sq. ft.
Power loading, 27 lb./h.p.
Maximum speed near the ground, 99 m.p.h.
Cruising speed, 93 m.p.h.
Climb to 3,280ft., 12 minutes.
Practical ceiling, 9,840ft.
Taking-off run, 110 to 130 yds.

Sikorski Reconnaissance or Mail Aeroplane. Type S.32-1925

L'Air. 1.2.26. (4526.)

This aircraft can be used as a five-seater reconnaissance aeroplane or for mails. It has three separate compartments—the rear one for the pilot, and the other two for passengers, mails or freight.

The wings are entirely constructed of duralumin and are fabric-covered. The fuselage is of square section steel tubing joined by bolts and rivets. The wheel undercarriage can be replaced by floats arranged with a shock-absorbing system.

The petrol tanks are in the top wing and are gravity fed.

A 400 h.p. Liberty engine is fitted, driving a Reed duralumin airscrew.

The chief characteristics are as follows :—

Span, 58ft. 4in.
Length, 36ft.
Wing area, 614.2 sq. ft.
Weight empty, 3,399 lbs.
Useful load, 2,200 lbs.
Total loaded weight, 5,599 lbs.
Wing loading, 10.88 lb./sq. ft.
Power loading, 13.1 lb./h.p.
Maximum speed near the ground, 135 m.p.h.
Cruising speed, 110 m.p.h.
Landing speed, 40 m.p.h.
Service ceiling, 15,100ft.
Climbing speed near the ground, 800 ft./mins.

Power Units

U.S.A.

Heavy Oil Engine Development

Aviation. 10.5.26. (5526.)

A two-cylinder aircraft engine which consumes very heavy oil has been developed experimentally by the Navy Department and is likely to be used as a basis for a more powerful engine of the same type for use in airships. This engine, it is believed, will greatly increase the safety of the rigid airship because the heavy oil fuel is not inflammable.

The new engine is the invention of A. P. Attendu, who has been interested in the development of a heavy oil engine for a great many years. The engine weighs only three and a half pounds per horse-power and is designed to develop 125 h.p.

MISCELLANEOUS

U.S.A.

Oil-Flow Tests

Aviation. 10.5.26. (6526.)

The characteristics of lubricants and lubrication systems with particular reference to the extent to which they are influenced by change in temperature are being studied by the Bureau of Standards of the Commerce Department under authorisation from the Bureau of Aeronautics of the Navy Department.

At low temperatures, such as are experienced at times by aircraft engines, oil may flow extremely slowly. For such conditions the dimensions of the pump and the feed lines must be sufficient to ensure adequate lubrication, and yet provision must be made to prevent over-oiling when temperature conditions are such that the oil flows freely. For the purpose of conducting the experiments, an air-cooled radial engine has been mounted in a "cold room" and provided with the necessary equipment for measuring oil flow under various conditions. Measurements with this engine are being paralleled by an experimental study of the pump and other elements of the lubrication system.

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